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Filmless Radiology: The Design, Integration, Implementation, and Evaluation of a Digital Imaging Network

Annual and Final Report

AD-A223 779

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June 1990

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Medical images generated by radiological procedures typically result in the generation of film-based images. In 1986, the U.S. Army Medical Research and Development Command contracted with the MITRE Corporation to investigate the use of filmless radiology in both its fixed facility and battlefield medical systems. To support this evaluation, commercially available Digital Imaging Network System (DINS) equipment was competitively procured and installed at two university medical centers, which competed for the opportunity to participate in this evaluation. Equipment provided by AT&T was installed at Georgetown University and equipment provided by Philips Medical Systems was installed at the University of Washington. In parallel, a prototype battlefield DINS was developed by MITRE, using commercially available workstation technology, to support concept exploration of DINS in the battlefield environment. This document summarizes and presents the results of the systems engineering studies and technical evaluations that were conducted as part of this four-year study.

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FOREWORD

For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45CFR56.

Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

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EXECUTIVE SUMMARY

BACKGROUND AND INTRODUCTION

Under the sponsorship of the U.S. Army Medical Research and Development Command, The MITRE Corporation installed and evaluated two Digital Imaging Network Systems (DINS) at university medical centers, and examined this technology for use in future Army fixed and battlefield medical facilities. To achieve these objectives, MITRE competitively selected Georgetown University, in conjunction with George Washington University, and the University of Washington to serve as evaluation sites. MITRE also competitively selected AT&T as the vendor for the equipment installed at Georgetown University, and Philips Medical Systems for the equipment installed at the University of Washington. The DINS project began in March 1986 and is scheduled to end in June 1990. The objective of DINS is to replace film-based radiological image management with filmless image management. In the filmless environment, images are acquired digitally, transferred over computer networks, stored on magnetic or optical computer storage media, and displayed on video monitors.

This report summarizes the detailed evaluations, technical studies, and cost studies that were conducted under the DINS project. For the most part, it is based on the final reports submitted to MITRE by the two universities. This report seeks to achieve the following objectives:

- To discuss the highlights and major accomplishments of the program in one document.
- To serve as the formal final report on the project to the sponsoring agency.
- To identify other documents that provide detailed information on selected DINS project activities.[1]

OVERALL PROJECT GOALS

From the outset, the scope of the DINS project was broad: to install and evaluate DINS at two university medical centers and to investigate uses of DINS technology in the battlefield medical environment. However, the technologies and issues involved in implementing filmless radiology in the peacetime and combat medical arenas constantly evolve. Considerable effort was directed to maintaining flexibility within the project regarding current technologies to assure that those being evaluated were relevant to the Army's future plans. The overall goals of the project were:

---

[1] Throughout this report, bracketed numbers refer to documents listed in appendix A.

- To gain experience in planning for and installing DINS within a medical facility
- To gain clinical experience with DINS equipment from an operational perspective.
- To identify features of DINS that either were suitable for use in future systems or required modification before a specification can be written.
- To demonstrate DINS technology to key Army personnel.
- To facilitate technology transfer.
- To apply experiences gained from the fixed facility evaluations to the battlefield medical environment.

SIGNIFICANT PROJECT ACCOMPLISHMENTS

The DINS project can be credited with a number of significant accomplishments with regard to the use of DINS for medical applications. These include:

- First full-scale use of DINS in a radiology department with links to other parts of the hospital and to remote sites
- First evaluation of filmless radiology in the combat medical environment
- First evaluation at Army medical centers of Computed Radiology (CR) employing phosphor plate technology
- First evaluation of teleradiology as a peripheral to a hospital image management system as distinguished from stand-alone teleradiology systems
- First demonstration of teleradiology linking overseas U.S. Army bases and Continental United States (CONUS) facilities

FIXED FACILITY DINS

Baseline data were collected from Georgetown University Hospital [2] and the University of Washington Medical Center [1] as part of the evaluation as summarized in section 2 of this report. These data characterize the size of the two facilities and the spectrum of services they provided prior to DINS implementation. Table 1 abstracts general data that characterize the two DINS test sites. These data are useful for comparing the two medical centers and, in the future, for comparisons with

Table ES 1
Size and Other Characteristics of the Test Site Hospitals

Hospital Characteristics	Sub-Category or Measure	Test Site	
		UWMC	GUMC
Size	Number of Beds	450	535
Utilization (Annual Data-1987)	Number of Admissions	13,231	20,202
	Average Daily Census	296	414
	Average Length of Stay (Days)	8	7
	Number of Outpatient Visits	162,783	127,844
	Number of Emergency Rm Visits	36,783	24,748
Hospital Medical Staff	Attending Physicians	391	600
	Senior Residents and Fellows	530	558
	Ward Practitioners	81	N/A
	Nurse Coordinators	29	29
	Nurse Specialists	14	38
	Licensed Practical Nurses	10	17
	Hospital Assistants	50	N/A
	Nurse Trainees	34	5
Radiology Department Staff	Attending Radiologists	10	20
	Physicist/Radiochemists	9	6
	Fellows	5	8
	Residents	11	13
	Technical Staff	35	36
	Support/Clerical Staff	40	113

N/A: This personnel type not represented at Georgetown University

Defense Department Medical Treatment Facilities. To characterize the radiology department workload, annual totals for medical imaging modalities at the two hospitals appear in table 2.

A number of technical evaluations were conducted at each university using the DINS equipment. These studies, and others, are documented in the University final reports and related technical publications [3][4][5]. Six key studies are referenced below, along with their major findings. They are discussed more fully in section 3.

- Fixed Facility Network Simulation--Bottlenecks were identified that impeded smooth operation of the system. However, users felt that the system could be made clinically acceptable [6] with minor improvements.

- Interface to Other Information Systems--Efforts were made at both evaluation sites to interface a Radiology Information Systems (RIS) or a Hospital Information Systems (HIS) to the DINS. However, there were limitations in the protocols available for moving data to the DINS, and data could only move in one direction from the RIS/HIS to the DINS. For full integration, two-way communications is considered essential. Requirements for interfacing future generic DINS to other military information systems, such as the Composite Health Care System (CHCS), were also investigated [15][16].

- Workstation Evaluation--Evaluations of the DINS workstations indicated that the displays must be faster and that the user interface needs to be more intuitive (i.e., simple and straightforward for the infrequent user).

- CR Evaluation--CR technology was considered satisfactory by its principal users. It serves as a replacement for film-type images and allows direct capture of digital radiographs by exposing and then scanning a phosphor plate in place of film. Improvements were recommended regarding user interface and the general system organization.

- Teleradiology--Teleradiology evaluations were conducted at both sites and the technology appeared to work well when coupled with the DINS.

- Image Acquisition--An evaluation of the system's image acquisition techniques indicated that future operational DINS must support interfaces to digital imaging modalities (e.g., Computed Tomography, Magnetic Resonance Imaging).

Additionally, cost modeling was performed at the University of Washington to estimate costs of future DINS installation and determined cost reductions required to justify future DINS implementations [20]. It was estimated that a DINS may be considered cost-justifiable if initial system costs, using 1988 figures, are reduced by 30 to 50 percent. Trends in the workstation industry, a primary component of a DINS, indicate that such a reduction is probable.

Table ES 2
Annual Number of Medical Image Procedures at Test Site Hospitals

Modality	Test Site	
	Washington	Georgetown
General Radiology	50,662	103,644
Mammography	2,166	8,574
Ultrasound	9,533	7,566
Computed Tomography	8,247	12,803
Magnetic Resonance	3,861	3,253
Angiography	1,020	1,459
Nuclear Medicine	2,166	8,641
Cardiac Radiology	2,572	2,360

BATTLEFIELD DINS

As discussed in section 4 of this report, one of the principal goals of the project was to extend the technology evaluated in the fixed facility environment into the battlefield environment. To accomplish this goal, MITRE documented the imaging needs of the Army's deployable combat Medical Treatment Facilities [7] and then developed an initial set of functional requirements [9]. This led to the design, development, and evaluation by MITRE of a prototype battlefield DINS. These requirements include:

- Image Acquisition
  - Direct acquisition of digital image data
  - Electronic capture of inter-facility image data
- Image Display
  - Rapid access and display of any image at any DINS workstation
  - Display of multiple images on a single screen
  - Adjustability of display by gray scale window width and level
  - Ability to display image in inverse video
  - Ability to rotate an image
  - Ability to flip and mirror displayed image
- Database Administration
  - Registration of new patients
  - Electronic capture of inter-facility patient data
  - Storage of all patient data on the local DINS until patient discharge or transfer
  - Interface to other battlefield medical information systems [14]
- Data Communications
  - Intra-facility transport of image data via electronic network or transportable data storage medium
  - Transportability of image data between hospitals or back to CONUS

To assist with the definition of requirements for future battlefield DINS systems, MITRE developed a model to simulate the flow of battlefield casualties through the Army combat medical care system [10]. The simulation focused on facilities in Echelon 3 of the system, the lowest echelon at which DINS is expected to be introduced. The basic assumptions regarding the flow of patients and medical images, as well as assumptions introduced for computational simplicity, were documented. This simulation showed that a typical peak estimated image storage requirement for an

Echelon 3 hospital was two Gigabytes, or approximately 1,400 film-type images. A 10 Megabits per second Ethernet local area network provides sufficient communication capacity for this hospital.

Based upon preliminary analyses, a prototype battlefield DINS was developed and subjected to evaluations. The results were positive, indicating that this technology is ready for evaluation in the battlefield environment.

CONCLUSIONS

The conclusions drawn from the evaluations of the fixed facility DINS and the battlefield DINS prototype are presented in detail in section 5 of this report, and summarized below:

- DINS will not be accepted operationally until interfaces to the modalities are fully digital and their operation is transparent to the users of both DINS and the imaging modality hardware.

- A completely functional interface between DINS and HIS/RIS remains a problem and is a key issue for operational acceptance.

- If DINS is to coexist in military medical facilities with CHCS, an interface must be defined so that

  - DINS can be adapted to the CHCS environment.

  - CHCS can be modified to interact with DINS.

  - DINS can be specified and procured with a proper interface.

- While still expensive, DINS implementation costs may drop significantly, following workstation technology cost trends, making an operational DINS more feasible from a cost viewpoint.

- Teleradiology is reaching the point where it is both operationally acceptable and cost justifiable.

- Speed of display and ease of operation are critical to user acceptance.

The evaluators at Georgetown University generally found the system to be acceptable, whereas the evaluators at the University of Washington found the system to be clinically acceptable, with reservations. A number of factors could have influenced this difference in opinion. It should be pointed out, however, that the Georgetown system contained two enhancements not included in the University of Washington system. a "Turbo" display workstation and automatic routing of images upon acquisition. While the Georgetown system actually experienced an overall lower throughput than that at the University of Washington, as determined during final system acceptance testing, operations as perceived by the clinical user appeared to occur faster in some cases.

RECOMMENDATIONS

Given the above conclusions, the recommendations made in section 5.2, are summarized below:

- Evaluate DINS in an operational military fixed-facility setting.
- Phase implementation of DINS. Do not attempt to reconfigure an existing radiology department in one operation.
- Use CR as the main source of plain film images for DINS.
- Develop a functional description for a DINS/CHCS interface.
- Continue to develop and evaluate the battlefield DINS prototype, and prepare the technical specifications for future battlefield DINS.

SECTION 1

INTRODUCTION

1.1 PROJECT BACKGROUND AND HISTORY

The Digital Imaging Network Systems (DINS) project began in March 1986. The two university evaluation sites, Georgetown University and the University of Washington, were selected competitively and placed under contract to The MITRE Corporation in September 1986. The vendors, AT&T and Philips Medical Systems, were also selected competitively, based upon specifications defined in *Technical Specifications for a Hospital Based Digital Imaging Network*, MITRE Technical Report (MTR-85W242). They signed as subcontractors to MITRE in August 1987.

Equipment installation began at Georgetown University in the spring of 1988 while installation at the University of Washington was delayed until the fall of 1988 due to changes in the configuration of the Philips equipment. A complete system was operational at Georgetown University by June 1989 and at the University of Washington by September 1989. While there were delays in implementing complete systems at each site, component evaluations took place prior to installation of the complete system. For example, the Philips Computed Radiology (PCR) system was installed at the University of Washington by September 1988 and evaluated in subsequent months. Each system was subjected to formal acceptance testing to assure proper operation of the system. Evaluation efforts and technical activities were completed by February 1990 and all documentation will be complete by June 1990. These milestones and other significant events during the course of the DINS project at MITRE are depicted in figure 1-1.

1.1.1 Significant Project Accomplishments

The DINS project achieved a number of significant "firsts" with regard to DINS medical applications, including the following:

- First full-scale use of DINS in a radiology department with links to other parts of the hospital and to remote sites
- First evaluation of filmless radiology in the combat medical environment
- First evaluation at Army medical centers of Computed Radiography (CR) using photo-stimulable phosphor plate technology [11]
- First evaluation of teleradiology as a peripheral to a hospital image management system as distinguished from a stand-alone system

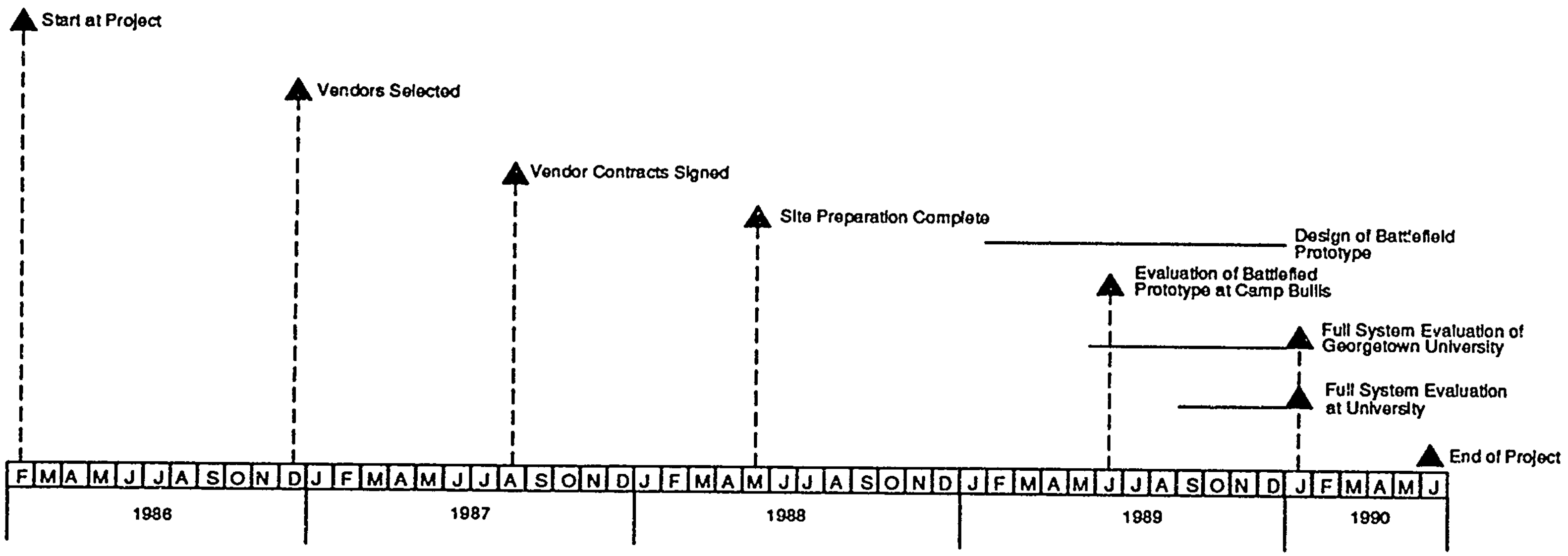

Figure 1-1
Project Timeline/Key Milestones

- First demonstration of teleradiology linking overseas U.S. Army bases and Continental United States (CONUS) facilities

1.2 PROJECT STRUCTURE

1.2.1 Project Management

The contractual structure of the DINS evaluation project is depicted in figure 1-2. MITRE was placed under contract to the U.S. Army Medical Research and Development Command to install and evaluate two DINS at two university medical centers, and to examine this technology for use in future Army fixed and mobile combat medical facilities. As described above, Georgetown University, the University of Washington, AT&T, and Philips Medical Systems were selected competitively and were subcontractors to MITRE under the project.

Project participants had the following general responsibilities:

- MITRE
  - Assume overall management responsibility for the project
  - Conduct competitive procurements for vendors and evaluation sites
  - Monitor the subcontractors
  - Monitor equipment acceptance tests
  - Investigate applications of DINS technology in combat medical facilities
  - Design, develop, and evaluate a prototype battlefield DINS
  - Coordinate feasibility briefings

- Georgetown University
  - Conduct pre-evaluation baseline studies at Georgetown University
  - Prepare Georgetown University hospital site for equipment installation
  - Develop and evaluate an interface between DINS and the University's Hospital Information System (HIS)
  - Conduct clinical and technical evaluations of the equipment
  - Serve as primary DINS demonstration site for military personnel

- George Washington University
  - Provide technical support to Georgetown University

- University of Washington
  - Conduct pre-evaluation baseline studies at the University of Washington
  - Prepare site for equipment installation

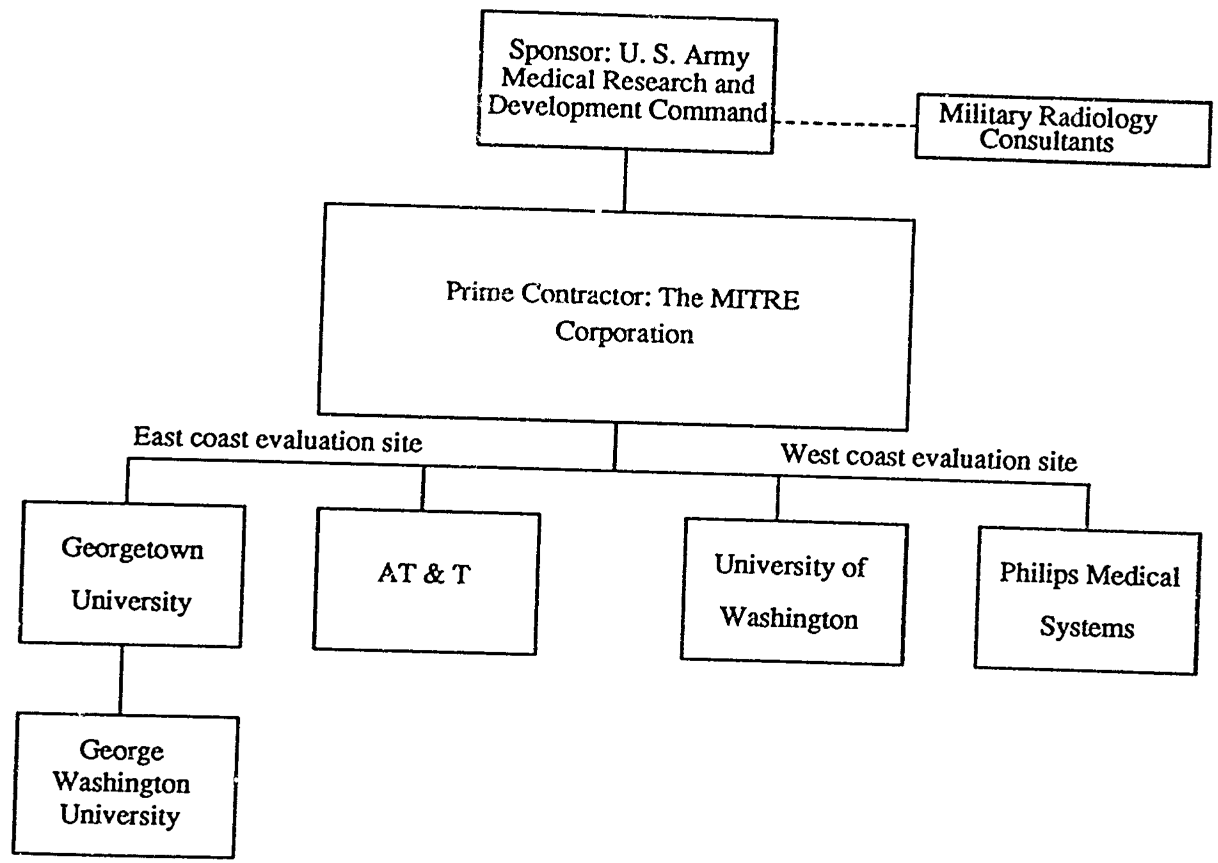

Figure 1-2
DINS Project Structure

- Develop and evaluate an interface between DINS and the University's Radiology Information System (RIS)
- Conduct clinical and technical evaluations of the equipment
- Serve as the "DINS mentor" for Army personnel at Madigan Army Medical Center

• AT&T

- Install DINS equipment at Georgetown University
- Maintain equipment during the course of the evaluation project

• Philips Medical Systems

- Install DINS equipment at the University of Washington
- Maintain equipment during the course of the evaluation project

1.2.2 Project Guidance

Technical efforts under the DINS project were guided by two documents, the project study plan [13] and the project management plan [12]. The latter document was issued as a draft in early 1987, published as a formal project document in November 1988, and revised in July 1989. The project study plan defined the basic goals of the project, including a list of questions to be addressed by studies under the project, and addressed the framework of the studies to be conducted. The project management plan prioritized the studies defined in the project study plan, assigned primary responsibilities for the participating organizations, and identified deliverables resulting from the various investigations.

1.3 OBJECTIVES AND APPROACH

The final report of the DINS evaluation project summarizes the technical and evaluative work performed on the DINS project over its four-year history. It documents the history of the project, outlines key investigation activities, identifies the parties involved in the evaluation, references literature published as a result of the project, and presents conclusions and recommendations resulting from the project. Readers are directed to appendix A for a list of documents and conference papers that address the accomplishments of the project in detail.

1.4 AUDIENCE

This document addresses topics of relevance to the following audiences:

• Management and staff of the Army medical command. The report serves both as the final report of the DINS project and as a brief summary of the evaluations that occurred under the project.

- Personnel in other military and civilian government organizations who anticipate implementing DINS at their facilities. Installation and operational experiences at the two university sites, as reported herein, can contribute to the success of future implementations.

- Members of the medical community, generally, and the radiological science community, specifically. This is the professional group that will be most critically affected if the DINS concept takes hold.

1.5 SCOPE

This report summarizes the formal products completed during the four-year life of the DINS contract. Highlights of the evaluation activities are discussed, and project conclusions and recommendations are presented. Material presented herein is intended to summarize, not replace, the source documents, which are referenced in the text and annotated in appendix A, Project Bibliography.

1.6 DOCUMENT ORGANIZATION

This introduction to the final report provides a brief project overview, including the objectives, approach, and major program milestones. Section 2 describes the systems installed at the two test site hospitals used for evaluation purposes. It also includes descriptions of the two hospitals, essentially a sample of the baseline data provided in more detail in other project deliverables [1][2], to support future comparisons with facilities operated by the Army. Technical studies addressing a variety of issues relevant to the fixed facility DINS evaluations are summarized in section 3. The battlefield system is treated in detail in section 4, which also includes a description of, and sample results from, the battlefield medical imaging workload simulation developed at MITRE. Section 5 presents the project conclusions and recommendations. Appendix A contains detailed project bibliographies for MITRE, the University of Washington, and Georgetown University.

SECTION 2

FIXED-SITE DINS IMPLEMENTATION

2.1 DESCRIPTION OF THE TEST SITE HOSPITALS

2.1.1 Site Characterization

This section presents data characterizing the two medical centers that participated in the DINS project as test sites. This information is identified by the term "baseline data," since it describes the test site hospitals prior to the implementation of DINS. These data serve to establish the size of the two facilities and the spectrum of services they provide. This information is intended to serve as a point of reference from which to view the medical centers' experience in the DINS environment. The medical center scope-of-service data may also be useful in the future for comparing these two hospitals with Department of Defense (DOD) medical treatment facilities (MTFs).

Table 2-1 presents commonly accepted measures for the physical size, the utilization, and the medical staffing for both hospitals. Table 2-1 also includes detailed medical staffing information for the hospitals' radiology departments. In each case the staffing data apply only to patient care at the medical center's principal hospital location. The data exclude staff who are largely or exclusively concerned with teaching or research, as contrasted with patient services. The annual totals for the different medical imaging procedures performed at the two hospitals appear in table 2-2.

2.1.2 The University of Washington Medical Center (UWMC) Radiology Department

This section briefly describes the baseline operations (i.e., before DINS implementation) of the Radiology Department of the University of Washington [1].

2.1.2.1 Managing Patient Information

The DECRad Radiology Information Systems (RIS), which supports the daily activities of the University of Washington Radiology Department, consists of modules to perform patient registration, scheduling examinations, patient tracking, film library management, diagnostic reporting, management function and reports.

Table 2-1
Size and Other Characteristics of the Test Site Hospitals

Hospital Characteristics	Sub-Category or Measure	Test Site	
		UWMC	GUMC
Size	Number of Beds	450	535
Utilization (Annual Data-1987)	Number of Admissions	13,231	20,202.0
	Average Daily Census	296	414.9
	Average Length of Stay (Days)	8.2	7.5
	Number of Outpatient Visits	162,783	127,844.0
	Number of Emergency Rm Visits	36,783	24,748.0
Hospital Medical Staff	Attending Physicians	391	600.0
	Senior Residents and Fellows	530	558.0
	Ward Practitioners	81	N/A
	Nurse Coordinators	29	29.0
	Nurse Specialists	14	38.3
	Licensed Practical Nurses	10	17.8
	Hospital Assistants	50	N/A
	Nurse Trainees	34	5.0
Radiology Department Staff	Attending Radiologists	10	20.0
	Physicist/Radiochemists	9	6.0
	Fellows	5	8.0
	Residents	11	13.0
	Technical Staff	35	36.5
	Support/Clerical Staff	40	113.5

N/A: This personnel type not represented at Georgetown University

Table 2-2
Annual Number of Medical Image Procedures

Modality	Procedure	Test Site UWMC	GUMC
General Radiology	Chest/ribs/sternum/abdomen	31,538	N.A.
	Extremities	8,822	
	Spine	3,170	
	Hips/pelvis	2,166	
	Shoulder	1,532	
	Miscellaneous	3,434	
	Total for Modality	50,662	103,644
Mammography	Total for Modality	2,166	8,574
Ultrasound	Obstetrics/gynecology	4,347	N.A.
	Abdomen	1,592	1157
	Retroperitoneum	1,144	1569
	Head/neck	667	1401
	Pelvis	620	974
	Extremities	515	--
	Abdominal		715
	Chest/breast	276	563
	Miscellaneous	372	1187
	Total for Modality	9533	7,566
Computed Tomography	Abdomen	2,260	2,843
	Head	2,235	5,215
	Chest	1,014	1,211
	Pelvis	891	1,309
	Orbit/Sella	767	431
	Spine	330	439
	Maxillofacial	305	--
	Neck	272	--
	Other	173	1355
	Total for Modality	8,247	12,803
Magnetic Resonance Imaging	Brain	1,749	1,247
	Spine	764	1,425
	Pelvis	556	65
	Extremities	290	282
	Abdomen	143	169
	Miscellaneous	112	38
	Chest	108	27
	Other	139	--
	Total for Modality	3,861	3253
Angiography	Total for Modality	1,020	1,459
Nuclear Medicine	Total for Modality	2,166	8,641
Cardiac Radiology	Total for Modality	2,572	2,360
Grand Total		80,227	148,300

N.A.: Data not available.

The University of Washington Radiology Department generates approximately 232 reports per day; the average length is 420 words and the transcription time averages 6.5 minutes per report. Completing a transcription of a radiologist's report depends on having the three copies (document, file, and doctor's) received in the file room. This system is in the process of being replaced. A digital dictation/transcription system has been installed. Turnaround time for reports is expected to decrease, while the number of reports is expected to increase.

2.1.2.2 Radiology Procedures

The procedures performed at the University of Washington include the following:

- General Radiology
  - Chest Exam. This exam consists of two views and is the most common general radiology exam.
  - General Exam. The procedure for a general exam, ankle or wrist, for example, is essentially the same as for the chest exam.
  - Gastrointestinal (GI)/Genitourinary (GU) Exams. These diagnostic radiology procedures involve the radiologist in the exam and may make use of a contrast medium.
- Computed Tomography (CT). A CT study is composed of cross-sectional images of particular body parts taken in successive small steps (about 3 mm). Results are stored in a three-dimensional matrix, allowing the image to be viewed from different perspectives.
- Magnetic Resonance Imaging (MRI). MRI uses a strong magnetic field to obtain images of cross-sections of the body. The time to take a series of images is primarily dependent on the part of the body being scanned.
- Angiography. For this procedure, catheters are inserted into the patient's blood vessels; a contrast medium is injected; and a series of images are obtained using a digital fluorographic system. There is at least one radiologist-angiographer, one technician, and one nurse present during this procedure.
- Ultrasound. Exam results are recorded on video tape; the ultrasonographer transfers significant images to hard copy as necessary. When the ultrasonographer has completed his/her preliminary exam, the radiologist takes one or more scans of the patient.

2.1.2.3 Support Procedures

The following Radiology Department support procedures, required for the preparation and storage of medical images, are described briefly:

- Film Processing. One of the critical baseline data elements is the amount of time spent processing hard copies of different medical images. Table 2-3 summarizes film processing time for different image modalities at the University of Washington, based on data that are about a year old (i.e., 1988) but that match more recent experience.

- Viewing/Searching for Images. Another major concern as the radiology operation moves from a hard copy to digital image operation is the change, if any, in the allocation of a radiologist's time. In the current system at the University of Washington, a radiologist typically spends the following fractions of his/her total viewing time searching for an image in each of the modalities listed:

  - CT/MRI: NA
  - Ultrasound: 9.5 percent
  - Angiography: 2.2 percent
  - GI/GU: 7.1 percent
  - Plain Films: 18.7 percent
  - Average, overall: 10.6 percent

2.1.2.4 Radiology Records

The file room is an integral part of the Radiology Department, providing access to a patient's medical images. The University Hospital keeps all master film jackets, containing all of a patient's medical images, for eight years from the date of the last entry in the jacket. They are kept in three separate areas within the hospital complex:

- Primary storage, located in the Radiology Department, for master jackets that have been checked out within the past four months.

- Secondary storage for films that have not been requested during the last four months but have been reviewed within the last two years.

Table 2-3
Average Time for Film Processing Activities at UWMC (Minutes)

Modality	Activity*				Total
	Transport	Process	Inspect	Package	
CT/MRI	0.22	1.80	1.00	2.86	5.88
Ultrasound	0.34	2.59	0.39	0.75	4.07
Angiography	NA	6.02	NA	NA	6.02
CI/GU	0.28	1.85	1.45	1.95	5.53
Plain Films	0.23	1.81	0 96	NA	3.00
All Modalities	0.28	2.22	0.90	1.88	5.28

* Transport: Transport film to processor.
  Process: Insert film into processor and remove when processed.
  Inspect: Check film to make sure that exam does not need to be repeated.
  Package: Collect films and place in folder.

- Results of pediatric examinations are retained until the patient is 18 years old and eight years have elapsed since the last date of service.

Table 2-4 summarizes the approximate amount of time the file room personnel spend on activities in each of the following categories:

- Collating reports
- Updating file jacket information
- Making loans
- Archiving files
- Administration

2.1.3 GUH Radiology Department

This section briefly describes the baseline operations, (i.e., before DINS implementation), of the Radiology Department at GUH [2].

2.1.3.1 Managing Patient Information

The Radiology Department is supported by the Hospital Information System (HIS) which includes support for radiology functions. The HIS modules include patient registration, chronological index of patient activity, film jacket tracking system, report generating system, and order entry.

2.1.3.2 Transcription Workload

During a two-week period in 1987, selected for baseline purposes, a total of 3,036 reports were typed. An average of 217 reports were generated per day, and the length of the average report was 111 words. For a sample of 100 reports, the average elapsed time between typing and signing of the report was 3.2 days. Approximately one-third of the reports were signed within one day.

Table 2-4
Activities of UWMC Fileroom Personnel

Task		Average Time (Hours/Day)
Collate Records		22.0
Update Jacket Information		17.0
Loans	Internal/Alternators Internal/Radiologists Hospital/Clinics Individual Practitioners External/Mail	38.0 9.0 12.0 3.0 8.0
Archiving	Monthly Film Move, Active to Inactive Annual Purge Movement From Inactive to Archives	1.25 1.4 0.6
Administrative		16.0

2.1.3.3 Radiology Procedures

The medical imaging procedures performed at the GUH include all of those shown in table 2-2. For purposes of estimating archival requirements and digital image processing workloads, the tabulated data provide estimates of the static load. For baseline purposes, the Georgetown team also attempted to examine the data movement, and dynamic traffic loading on the image processing system. For this purpose, they focussed on two imaging modalities:

- General Radiology. At the Georgetown University the general radiography service is responsible for chest, pediatric, and bone radiography studies. The average daily image generation rate is approximately 500 on weekdays and 300 on weekends. The weekday maximum image generation rate occurs in mid-morning; the weekend imaging rate exhibits maxima in the middle of the morning and at the end of the afternoon.

- Computed Tomography. Georgetown University covers two services, neurological and abdominal imaging, with its two CT scanners. During a two-month data collection period, the monthly average of 682 cases generated 20,000 image frames.

2.1.3.4 Support Procedures

This section describes the general flow of the work in the Radiology Department, introducing and briefly describing the department's support functions. The principal steps in the work flow are described as follows:

- Generating the images. The different divisions of the department maintain the protocols by which images are initially generated. Once the images are acquired, they are processed by radiology technologists. Hard copies of the images are taken to the designated film alternators or directly to the film library.

- Mounting at alternators. Technologists bring the new images to the designated alternators. They are loaded by technologists, film library clerks, or residents. The cases are recorded in a log book kept at the alternator. During a designated period of the day, radiologists review the cases and record an abbreviated diagnosis in the log book and on film inserts. The images and film jackets are removed from the alternators and taken to the 24-hour file, described below, by the film library staff during the night shift.

- Generating reports. The reports that have been dictated are transcribed into the RIS; they are then accessible to physicians in the hospital on the RIS and HIS video terminals throughout the hospital. The signed report is printed and sent to the medical record, and to the referring and admitting physicians.

2.1.3.5 Film Library

The images are placed in the library for use by the hospital medical staff, transmission to other hospitals, and other applications. The film library uses two types of envelopes in which to keep the films:

- Inserts that contain images organized by category, such as CT, MRI, ultrasound, bone, chest, and others. The inserts are then placed inside a master jacket.
- Master jackets, each of which represents one patient. Radiology Department rules state that a master jacket never leaves the library.

The HIS film library management module keeps track of the inserts but does not track individual images.

The Georgetown film library is organized in four levels of storage, defined as:

- The 24-hour file holds the current day's work as it comes back to the file room, and the work done late the previous day.
- The active file maintains the images for the most recent six to nine months.
- The intermediate file holds images up to 24 months. A typical retrieval time for an image in the intermediate file is approximately two hours.
- The archival storage facility, at a remote site 12 miles from the hospital, keeps images for longer periods. It typically takes on the order of two days to retrieve an image from the archives.

For most patients, films are maintained in the film library for a minimum of five years after the last date of service. For those patients who have had angiography, ultrasound, nuclear medicine, computed tomography, or mammography services, the films are maintained for at least ten years after the last date of service. Results of pediatric examinations are retained until the patient is 18 years old and eight years have elapsed since the last date of service.

2.1.3.6 Use of the Film Library

Patient images are requested by individual physicians and clinical services. Images are checked out to the physicians over the counter at the library. This section describes the two categories of users in turn. The detailed Georgetown University data appearing here, describing the use of the film image library, the users of the library, and the loans from the library, are based on a survey of medical image film library users conducted during one summer week in 1987.

- Individual users. Table 2-5 summarizes several results of the survey. The table shows, for example, that 60 percent of the users of the film library are either residents or attending physicians. The results also show that 77 percent, or approximately three quarters, of the folders drawn from the library were held out for only one day or less.

- Use by medical services. The Georgetown University study team collected medical image check-out data by reviewing every film request from the hospital's medical services during a one-week test period. Different departments and services request a list of patient jackets for conferences and research purposes. Out of a total of 827 jackets requested during the data collection week, 534 were found. The remaining 293 jackets were not located for the following reasons:

  - 187 were for new patients with no previous studies
  - 9 jackets had no films or inserts
  - 22 jackets were signed out to someone else
  - 75 represented special data problems

The data problems indicated above include ambiguous or incomplete patient information, duplicate names, and duplicate patient identifications (IDs).

2.2 THE DINS INSTALLATION AT THE TEST SITES

2.2.1 Georgetown University Installation

The DINS installation for Georgetown University is depicted in figure 2-1. The basic components of the system and their general technical characteristics are as follows:

- Software configuration--CommView® release 3.0.1, RIS interface (version of 7 December 1989), Kermit version 4E.

- Data Management System (DMS)--The DMS serves as the central hub of the DINS. As depicted in figure 2-1, the DINS uses a star topology. The DMS supports access by a total of up to 11 devices via fiber optic links (additional fiber optic links are possible using manual switching or a patch panel), and both leased and dial-up telephone lines. The DMS also supports mirrored magnetic storage of images with a total capacity of 10.4 GBytes.

CommView is a registered trademark of AT&T.

Table 2-5
Survey of GUH Medical Image Film Library Users

Category of Variable	Variable or Class Interval	Percent of Category
Users (427 Responses)	Resident	39
	Attending Physician	21
	Student	17
	Fellow	13
	Other	8
	Patient	2
Reasons for Request (441 Responses)	Personal Review	6
	Consult with Other Radiologists	14
	Other	10
	Clinical Conference	9
	Take to Another Facility	3
Length of Possession (412 Responses)	Less than 1 Day	31
	1 Day	46
	1 Week	4
	2 Weeks	1
	Other	18
Number of Requests per Week (153 Responses)	More than 15 Cases	25
	10-15 Cases	18
	5-9 Cases	36
	Fewer than 5	21

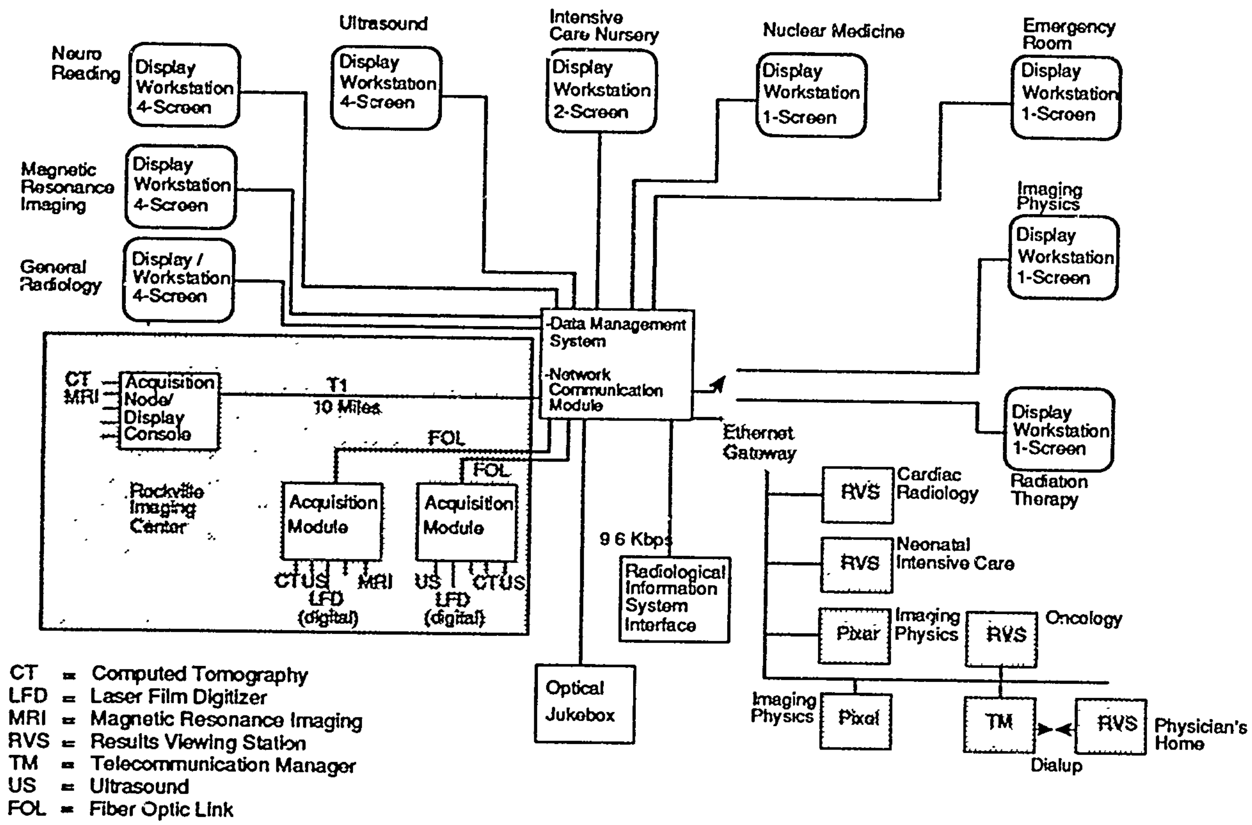

Figure 2-1
Georgetown University Digital Imaging Network System

- Optical Jukebox--The optical jukebox serves as the archival storage system for the DINS. It contains 89 twelve inch Write Once, Read Many (WORM) platters, each of which can store 2 GBytes of data. The jukebox supports two optical platter disk drive units; however, only one drive can be accessed. Each platter can hold approximately 8,000 512 x 512 8 bit uncompressed images.

- Results Viewing Stations (RVS)--The RVS is a low-end PC based workstation supporting a single screen display. This device was used primarily to support non-diagnostic image display in several hospital wards via Ethernet and at the home of one radiologist via a dial-up telephone link.

- Results Viewing Station Gateway--The RVS gateway provides a one-way image link from DINS to Ethernet.

- Acquisition Module (AM)--The acquisition modules are used to acquire images from the various modalities into the DINS. Video frame grabbers were used to re-digitize images from CT, MRI and, Ultrasound, and digital images were accepted directly from laser film digitizers (and CR, in the case of the University of Washington.) The AMs also support a DR-11 parallel digital interface, currently used to connect to the laser film digitizers. A new version of the AM, the 32 bit AM, has been received and will support the ACR-NEMA digital interfaces for MRI and CT.

- Four-Screen Enhanced Display Workstation (EDW)--The four screen display stations supports four 1280 x 1024 gray-scale monitors and basic image manipulation capabilities. Local disk storage is available at each of these workstations. The "turbo" package, installed on the workstations in Abdominal Imaging, General Radiology, and Neuroradiology, provides for increased image display speed and expanded local disk storage.

- Two-Screen Enhanced Consultation Workstation (ECW)/AM--The two screen displays supports both display and acquisition of images.

- Laser Film Digitizer--The laser film digitzer supports acquisition of images into the DINS of images that have already been committed to film. The approximate resolution of the laser film digitizers used on the DINS project is 2048 x 2048 x 12 bits.

- Research Image Processing Stations--The research image processing stations at Georgetown University consist of a Pixar Image Computer and an AT&T Pixel machine. These stations are used for advanced image processing research and investigation of potential workstation designs and are able to receive images from DINS via Ethernet.

- HIS/DINS Interface- The HIS interface consists of a desktop computer that communicated with the in-house HIS and with the DINS, using the Kermit protocol.

2.2.2 University of Washington Installation

The DINS installation for the University of Washington is depicted in figure 2-2. The system configuration at the University of Washington was essentially the same as that at Georgetown with the following exceptions:

- Number and placement of workstations.
- Integration of a Philips Computed Radiography (PCR) system at the University of Washington. PCR combines conventional radiographic techniques with stimulable phosphor, laser, and computer technology to produce digital X-ray images. The primary function of PCR is to acquire, process, and transmit high-resolution (up to 2510 x 2000 with 10 bits per pixel) X-ray images employing reusable stimulable phosphor image plates in place of conventional film/screen detectors.
- Dedicated 1.544 Mbps T1 leased line communications to the Harborview Medical Center (Seattle, WA), VA Medical Center (Seattle, WA), and Madigan Army Medical Center (Tacoma, WA).
- Use of a long distance teleradiology link to Alaska at the University of Washington.
- The research image processing station at the University of Washington was configured differently than at Georgetown, consisting of a Pixar image computer, a MegaScan high-resolution display monitor, and a parallel transfer disk capable of performing high-speed updates of the MegaScan monitor display.
- The DMS at the University of Washington was configured with 5.4 GBytes of mirrored magnetic disk storage.
- Interface to a DECrad RIS.
- "Turbo" workstations or image routing capabilities not supported by the University of Washington DINS.

2.3 EVALUATION OF TEST SITE INSTALLATIONS

Evaluations at the two sites generally proceeded according to plans laid out in the project study plan and project management plan. The activities fell into two categories:

- Technical evaluation--evaluation of various technical aspects of the system including display image quality, network performance and interfacing issues

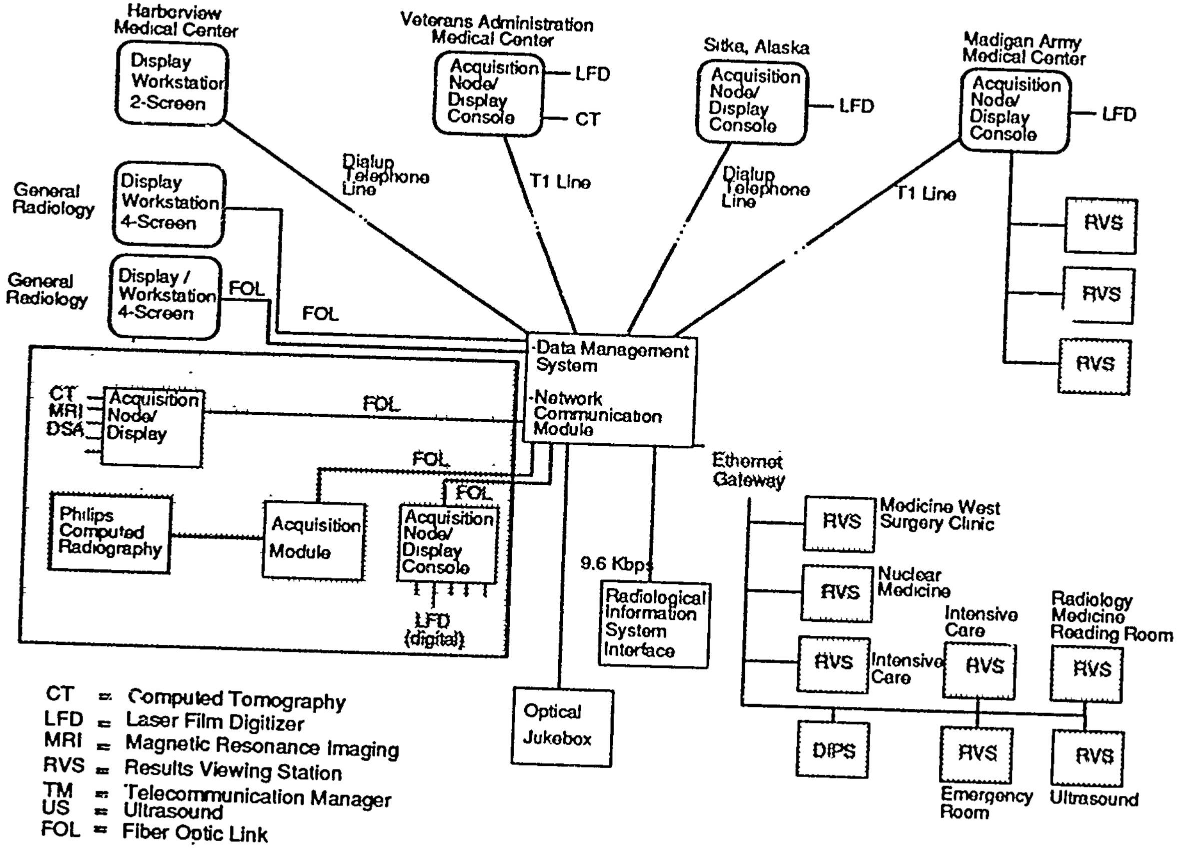

Figure 2-2
University of Washington Digital Imaging Network System

- Clinical evaluation--evaluation of the medical professionals' reactions to various aspects of the system and its overall effect on clinical practice.

Details regarding these evaluations are discussed in each University's final project report [3][4] and in other papers and publications listed in appendix A. Key conclusions and recommendations from the fixed facility evaluations are included in section 5 of this document. Selected studies and evaluations conducted at the University sites are abstracted in section 3 of this document.

SECTION 3

SELECTED TECHNICAL INVESTIGATIONS AT THE UNIVERSITY SITES

A number of technical evaluations were conducted at each site using the DINS equipment. This section presents a brief overview of some of the key activities conducted. The University final reports and conference papers contain more detailed information on these activities.

3.1 NETWORK SIMULATION

3.1.1 University of Washington Network Simulation

In order to better identify bottlenecks in the design of the DINS, the University of Washington developed a simulation model of the system. As the system installed at the University was proprietary, it was not possible to modify system software to incorporate automatic collection of data using check points within the system. Therefore, baseline input for the model was generated by observing the system's physical response to various stimuli (e.g., request display of an image and wait for the image to be displayed and observe the indicator lights on the communications module.)

3.1.1.1 Results

The following results were obtained from the University of Washington simulation studies:

- The central database unit, Data Management System (DMS), becomes the global bottleneck when more than four modes of the DINS ask for services simultaneously.
- The image acquisition and compression times at the image capture units, and the decompression time at the display workstations are some of the local bottlenecks.
- The teleradiology link to Alaska did not seem to degrade system performance during the network modeling exercise. However, the teleradiology link was found to degrade system performance in subsequent acceptance testing of the system.

3.1.1.2 Conclusions

Based upon the results obtained from the simulation studies, the University of Washington believed that the system was not yet ready for clinical use due to slow system response. However, if the causes of this slow response were removed and system performance were improved, then the system could be considered clinically acceptable [6].

3.1.2 Georgetown University Network Simulation

Georgetown University carried out modeling of the DINS at a different level from that done at UW. The model was built on operational characteristics, and viewed devices as queueing systems. While real-world values were used to establish operating parameters of the system simulation, it did not build a detailed communications network model (for example, simulation down to the data packet size). A number of studies were carried out using the queueing model, and were compared with actual systems performance. Both acquisition and display were successfully modeled, and helped reveal reasoning behind some systems design. An important example is in the acquisition model; it was shown that the bias the Acquisition Module (AM) software builds in towards minimizing input queue length is a valid one, since it will result in a minimum wait time for the technologist acquiring the images on clinical services. The success of these studies also prompted GUH to use the model in a predictive way. The impact of adding a fourth ultrasound machine on either of the two AMs was modeled. In the process, the model helped illustrate how unevenly loaded the AMs were, and the result was a reconfiguration of the real DINS.

The GUH experience was that the overall operational model could be used to verify system designs and to optimize the configuration of the equipment on the network. While the DINS operated satisfactorily at GUH, the simulations helped point out ways in which modifications could be made so as to minimize the impact of additions or changes.

3.2 RIS INTERFACE ISSUES

The DINS at each evaluation site was interfaced to the facility's existing RIS or HIS for the purpose of downloading patient data to the DINS. At each site, the interface was limited to uni-directional data transfer from the RIS/HIS to the DINS. More information on this topic can be found in each University's final report and assorted conference papers. Additionally, MITRE investigated the requirements for interfacing DINS to other military information systems, such as the Composite Health Care System (CHCS) [15][16].

3.2.1 RIS Interface at University of Washington

The RIS used by the University of Washington Department of Radiology is the DECrad system. The interface between DECrad and the DINS was implemented on an desktop computer. The desktop computer was interfaced to the DINS via a serial interface running the KERMIT communication protocol. Communication between the desktop computer and DECrad occurred over an 8-port serial communication interface. The DINS accepted the following transactions from the RIS:

- Add/modify/delete patient
- Merge patients
- Add exam/modify/delete
- Merge exams
- Add/modify/delete report
- Audit

The RIS interface was found to behave unreliably, with the link frequently failing to operate. When operational, the link tended to degrade performance of the DINS. Furthermore, it was felt that the DMS did not have the computing power necessary to service the RIS interface while serving the DINS workstations. These problems and their cause are discussed in some detail in the University of Washington final report. Due to the problems encountered, the University of Washington staff considered the operation of the RIS/DINS interface to be unacceptable for clinical usage. Their recommendations for improving this situation include:

- The American College of Radiology/National Electrical Manufacturer's Association (ACR/NEMA) RIS/HIS/PACS message format should be used when that format is released (expected in late 1990), and a more efficient communication protocol than Kermit should be considered. Improved error handling and error recovery are required.
- The RIS identifier must be used in the DINS as the RIS initiates all cases. A manual means must exist for entering this identifier into the DINS if the RIS/DINS interface fails.
- Two-way communication is required so that the DMS can request the initiation of a required transaction.

3.2.2 HIS Interface at Georgetown University

Though the GUH experiences in designing and testing of the HIS/DINS were similar to those encountered at UW in terms of the hardware selected and protocol used for communication, the method used for the interface and the software environment were different. The version of the interface being used at Georgetown ran for over five months without technical problems and was clinically useful. Through the capture of the HIS radiology order information, the technologists were freed from having to re-enter the patient demographic information when setting up acquisition at the modalities. Some operational issues regarding the interface still need to be addressed by the GUH HIS managers and the DINS vendor, but these would result in additional enhancements to the interface and are not necessary to enable its basic operation.

The HIS-DINS interface at GUH did not cause any degradation of system performance. No change in image capture, transfer, or display time was seen as a result of running the HIS interface protocol. The protocol uses the ACR-NEMA data set structure, which, at present, is the only widely accepted standard for this interface. The GUH team recommends using ACR-NEMA structure. It is very likely that an ACR-NEMA standard that specifically addresses the HIS/RIS/DINS interface issue will be produced. Such a standard is in development at present, and will follow other standards (e.g., HL7, IEEE Medix) in this development.

3.2.3 MITRE Evaluation of DINS/CHCS Interface

The requirements for interfacing DINS to CHCS were examined and various possible implementation configurations were examined. Configurations varied from logically separate DINS and CHCS with one-way or two-way communication to a logically similar system supporting both DINS and CHCS functions. The advantages and disadvantages for each approach were evaluated and documented. It was recommended that, once DINS prototypes had been evaluated, a functional description should be developed for incorporating the DINS interface into CHCS. This interface definition must then be included in any specifications for future DINS for military environments.

3.3 WORKSTATION EVALUATION

3.3.1 Clinical Workstation Evaluation at University of Washington

The University of Washington conducted an evaluation, using the installed equipment, to determine optimal requirements for DINS workstations. The evaluation methodology and workstation specifications are discussed in detail in the University of Washington's final project report. The workstation evaluation was conducted primarily by exposing the workstations to experts in radiology and human-computer interactions and requesting that these individuals answer a detailed evaluation questionnaire. The general conclusions and recommendations coming from this study were as follows:

- The speed of the basic DINS workstation display (8-second image display time) was not sufficient for radiology applications. However, the display time for the research imaging station (1.5 seconds per image) was considered to be clinically acceptable.

- The reviewers felt that two screens were needed for a minimal capability display station (e.g., RVS) and that more than four screens were required at the larger diagnostic workstations.

- The user interface must be more intuitive.

- An intelligent scheme for automatically routing images to appropriate workstations in advance of a clinical review session is desirable (such an auto-routing scheme was installed at Georgetown University late in the evaluation).

3.3.2 Research Workstation Evaluation at University of Washington

The University of Washington implemented a prototype electronic alternator utilizing an advanced image processing workstation and evaluated its clinical acceptability as a primary diagnostic workstation. The goals of the study were to utilize the unique features of the workstation (large image memory of 72 MBytes, a high-speed parallel transfer disk, and a 2560 x 2048 high-resolution image monitor) to demonstrate the feasibility of a limited model of the electronic alternator as a primary diagnostic workstation in the DINS environment, to evaluate its capability in image viewing and diagnosis, and to assess the feasibility of an icon-based user interface to select and rearrange images on the monitor. The general conclusions from this study were as follows:

- Using currently available hardware, the display speed of the locally stored images was fast enough to be clinically acceptable to radiologists in making primary diagnosis.

- The icon-based user interface was quite acceptable.

- The spatial resolution (2560 x 2048) and its image quality were acceptable.

- The contrast resolution of only 8 bits per pixel was not adequate for use in an electronic alternator displaying medical images for primary diagnosis.

- The functions provided by the separate text monitor should be integrated into the image monitor.

3.3.3 Workstation Evaluation at Georgetown University

Georgetown University had the opportunity to evaluate the original display workstations (DW), the enhanced graphics DW (EGDW), the "turbo" EGDW, and the single-screen RVS. Clinical use of the workstations increased as their speed and capability increased. The DWs were primarily used for review of cases for comparison; no primary reading was done. The EGDWs were the first (in four screen configuration) to be used for primary interpretation. The neuroradiologists used an EGDW to read some of the MRI cases from the Montgomery Imaging Center.

The major change in use patterns developed when the "turbo" EGDWs were installed. This upgrade increased local storage capacity to 1.3 Gigabytes (about 2,100 images of 512 x 512 x 8 bit size) and made a marked improvement in display speed. From the local disk, the time to fill a screen with 20 images of 512 x 512 x 8 bits was improved from 24 seconds to 7 seconds. For a full-screen display of a digitized film (1684 x 2048 x 12 bits in memory, 960 x 1024 x 8 bits displayed), the time improvement was from 8.6 seconds (very close to the UW measured 8 seconds for CR images) reduced to 3.2 seconds. The remote display times were not as dramatically reduced, since communication protocol overhead erodes some of the advantage. In spite of this, reductions in the range of 25 - 30 percent were measured.

In addition to the improved speed, new software allowed for automatic routing of examinations to workstations. This allowed building of real work lists, and prompted the Ultrasound Section to begin primary reading at the workstation for about 50 percent of its cases.

3.4 COMPUTED RADIOGRAPHY EVALUATION

The University of Washington conducted clinical and technical evaluations of the PCR system installed as part of their DINS (figure 3-1). These evaluations are discussed in detail in the University of Washington's final report; however, key points and results of that evaluation are abstracted here. Phosphor plate technology was also evaluated by MITRE at Ft. Meade and Ft. Bragg Army hospitals [11]. Additionally, Georgetown University conducted evaluations of film digitizers.

3.4.1 Evaluations at the University of Washington

3.4.1.1 Equipment Description

The PCR system uses phosphor plate technology to directly acquire radiographic images without first going through the process of generating films. A cassette (with the same physical dimensions as a standard film cassette) containing the phosphor plate is placed behind the patient as

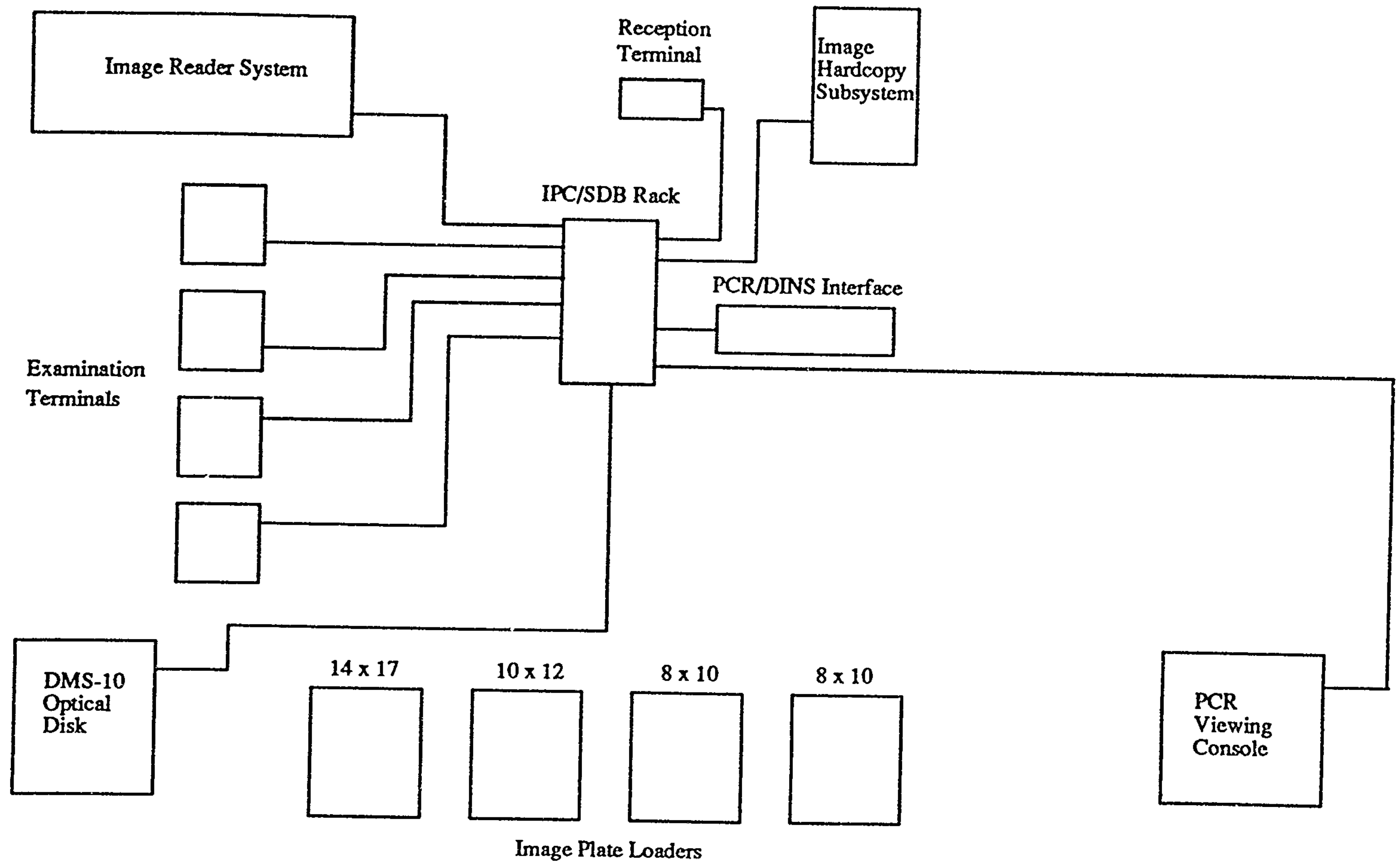

Figure 3-1
UWMC PCR Configuration

would a standard film, and the patient is X-rayed in standard fashion. The phosphor plate cassette is then placed into a reader that extracts a digital image with a resolution of 1760 x 2140 x 10 bits for a 14-inch by 17-inch X-ray format. Images are produced on film via a laser film digitizer and can be retrieved at the image processing station. An optical disk unit provides image storage for the PCR. A one-way image interface allows transfer of digital images from the PCR to the DINS.

The advantages of CR technology include the following:

- Film and chemicals are not required, thus allowing true filmless radiology.
- Digital images can be enhanced through the use of image processing, primarily, edge enhancement.
- Image quality can be improved through digital compensation, thus improving overall image quality and reducing patient X-ray exposure due to retakes of poorly exposed images.

3.4.1.2 Results of the PCR Evaluation

Technicians generally appreciated the image enhancement capabilities, automated management of images, and elimination of repeat procedures. However, the following recommendations were made:

- Overall operational complexity must be reduced, including user interface, system response to user errors, consistency in the user interface and overall system configuration.
- Sufficient training must be provided for new users.
- Easily performed, automated quality control procedures must be implemented and run at regular intervals.

3.4.2 MITRE Filmless Radiology Evaluation

Filmless radiology was also evaluated at two Army medical centers: Womack Army Medical Center at Ft. Bragg, North Carolina, and Kimbrough Army Community Hospital at Ft. Meade, Maryland. The results of the two 30-day examinations of the filmless radiology system led to tentative but significant conclusions concerning the likely value to the Army of an appropriately configured filmless system. These conclusions appear below.

3.4.2.1 Conclusions Concerning Clinical Acceptability

The system achieved considerable acceptance from radiologists and radiological technicians at Ft. Meade and Ft. Bragg during the evaluation periods. This was true despite the fact that the system was viewed as experimental and was not specifically configured to meet the requirements of either test hospital. The high potential value of the system in combat casualty care was widely acknowledged among clinicians at both hospitals.

3.4.2.2 Conclusions Concerning Image Quality

Based on laboratory studies on filmless technology, prior field studies employing filmless technology in general, and the clinical judgment of radiologists using the system during the examination, the system is capable of very high quality images. In some instances, this quality is higher than that of film, due to the system's ability to compensate for certain shortcomings in X-ray technique. In the opinion of all radiologists who used the system, it produces images that are adequate for the majority of cases in peacetime fixed facilities and that exceed image quality requirements during combat casualty care.

3.4.2.3 Conclusions Concerning Ruggedization

The system used during the examination was not ruggedized, but in the opinion of experts on the subject, there are no significant technical barriers to making the system sufficiently rugged to be field-deployable. This conclusion should be verified by testing an appropriately redesigned system against applicable field performance criteria.

3.4.2.4 Conclusions Concerning Teleradiology Capabilities

The system can be made fully compatible with all requirements for teleradiology links among fixed facilities. Though untestable during the examination, it seemed likely that the same performance could be expected among combat care facilities since the technology underlying teleradiology is well established.

3.4.2.5 Conclusions Concerning Costs and Benefits

An appropriately configured system has the potential for reducing the cost of radiology. Major cost reductions can be achieved by eliminating film, film processors, chemicals, and film storage. Important cost savings associated with the time spent by radiologists and technicians handling cases can also be realized. Potential benefits associated with the system can be achieved in the area of image acquisition, archiving, display, and inter-departmental and inter-facility communication.

3.4.3 Evaluation of Film Digitization at Georgetown

While the Georgetown CR facility was not included as part of the DINS, film digitization was investigated as a method for introducing plain film images into the system. Two DuPont laser film digitizers and a Konica laser film digitizer were used.

Film digitization is used clinically at Georgetown, though engineering studies of the digitizer performance showed them to be minimally acceptable. Problems were noted with noise, resulting in 12- bit data that contained usable information in only the top 8 or 9 bits. Despite these difficulties, the resulting images have been used clinically, but not for primary reading by radiologists.

A far more serious problem with the digitizers has been reliability. Until effective methods of preventive maintenance were used (primarily carefully cleaning the digitizer electronics bay), the digitizers would rarely run for more than 24 hours without having to be reset. Downtime has been significantly reduced, but still exceeds that of other devices on the network.

The technologists have been excellent at accepting the use of the digitizers even though it adds a step to their work flow. Operation of the laser digitizers is not difficult, and compliance is nearly 100 percent.

Because of the reliability issues, image noise problems, and workload for users, this method of acquiring plain radiographic images cannot be recommended for general use. For acquisition of a few images, or importing images that are only available on film, the technique is acceptable. In the mode tested at Georgetown, film digitization will not support input of the entire plain film load of a typical teaching hospital.

3.5 TELERADIOLOGY EXPERIENCES

Teleradiology was evaluated extensively under efforts previous to the DINS evaluation project. The initial concept of teleradiology was that image acquisition and transmission equipment located at multiple remote medical clinics would send digital copies of images to a central location for review by radiologists. Under DINS, this concept is modified slightly: i.e., remote site teleradiology systems are now considered peripherals to the DINS system, much as a computer printer is peripheral to a desktop computer, and the central reading site is not merely a reading site for teleradiology images but is an image management system for the hospital and the remote sites. Teleradiology workstations can be viewed as an extension of the hospital's image management system.

3.5.1 Georgetown University Teleradiology Experience

Experience with teleradiology was gained at Georgetown primarily through two routes: remote access by the Montgomery Imaging Center (MIC) and by using a workstation from a physician's home (see figure 2.1). During the course of the DINS project, Georgetown University operated the MIC on an outpatient basis. The Siemens CT and MRI units were interfaced to an AM at the MIC, and images were transmitted 15 miles to Georgetown University via a T1 link at 1.544 Mbps. The primary use of this link was to facilitate consultation between the staffs at Georgetown University and the MIC. In 1988, 1030 CT and 1,174 MRI examinations were performed at the MIC in consultation with Georgetown University.

The main users of the MIC teleradiology link were the neuroradiologists. They did primary reading, preliminary reading, and completeness evaluation using the system. The films from cases reviewed on the workstation were reviewed the next day, and over the period of the evaluation, no significant problems in interpretation from the workstation were found.

A link to one radiologist's home has been in place since July 1989. It is used for reading ultrasound cases when he is on call. He has found that during the average week of on-call coverage, he reads approximately four cases on the system. This translates into avoiding a trip in to the hospital about 80 percent of the time. The remainder of the time, the examination is one he must perform personally. The use has been successful, and plans are underway to install a second unit at another radiologist's home. All data communication is over voice-grade telephone lines using an adaptive modem. If line conditions are good, a 19.2 kilobit per second rate can be achieved. A typical display time is 59 seconds to paint a 512 x 512 x 8 bit image as it is being received. This timing is based on using low (2:1 lossless) compression.

In other tests and demonstrations of teleradiology, images were sent successfully from Georgetown to San Antonio, Texas, San Diego, California, Denver, Colorado, and Seoul, Korea. These were all accomplished using voicegrade telephone lines with the same modems used for the local teleradiogy links.

3.5.2 University of Washington Teleradiology Experience

Experience with teleradiology at the University of Washington was gained primarily through teleradiology links with Sitka, Alaska, the Seattle VA Medical Center (VAMC), and Harborview Medical Center (figure 2.2). The characteristics of these three sites are listed below:

- Sitka, Alaska
  - Equipment: AM, Laser Film Digitizer (LFD)

- Link: 4800 baud dial-up
- Distance to UW: 800 miles

- VA Medical Center
  - Equipment: AM, LFD, interface to CT scanner
  - Link: 1.544 Mbps T1
  - Distance to UW: 10 miles

- Harborview Medical Center
  - Equipment: Consultation Workstation
  - Link: 1.544 Mbps T1
  - Distance to UW: 5 miles

Data were generated by the LFD at a resolution of 1280 x 1024 x 12 bits and reversibly compressed to a ratio of between 2 and 2.5:1 prior to transmission.

The teleradiology evaluation ran for a period of 21 weeks. Following is a summary of the case loads transmitted from Alaska and VAMC to the University of Washington:

	Alaska Studies	VAMC Studies
Chest	60	48
Spine	36	27
Extremities	61	43
Abdomen	20	25
Skull	32	11
Ultrasound	48	0
CT	0	26
TOTALS	257	180

The conclusions of this evaluation were as follows:

- Reliable, high-speed communication is required for the teleradiology links to be considered acceptable. University of Washington staff generally found the 4800 baud link to be unacceptably slow.

- Teleradiology image quality from digitized film was judged to be acceptable for many applications, marginal in some (e.g., mastoiditis, infant respiratory distress syndrome), and unacceptable in others (e.g., mammography).

3.6 VIDEO IMAGE ACQUISITION STUDIES

3.6.1 Video Image Acquisition Studies at the University of Washington

The DINS equipment used at both Georgetown University and at the University of Washington used frame grabbers to acquire images from modalities that currently generate video output (CT, MR, Ultrasound). The frame grabber functions by capturing the video signal being sent to a display monitor by the modality. This technical approach has the advantage of allowing an external system to acquire images from the modality without having to modify the modality, through the addition of interface hardware and software, to support a computer network interface. The disadvantage is that the frame grabber is re-digitizing a signal that had once been digital and was converted to analog for display on the modality's video monitor. This second signal conversion results in significant degradation of the resulting image when compared to the original digital image.

3.6.1.1 Evaluation Methodology

To evaluate the frame grabber acquisition scheme, several digital image phantoms were generated on the General Electric (GE) CT9800 CT scanner, displayed on the console display monitor, and captured by the DINS. Once captured, these images were routed through the DINS and sent to an RVS where they were transferred to floppy diskette and moved to an image analysis computer. This procedure was repeated using the GE Signa MRI scanner and Society of Motion Picture Test Engineers (SMPTE) test pattern.

3.6.1.2 Results

Analysis of the images acquired using the DINS frame grabber yielded the following results:

- The resulting images were characterized by approximately two percent interference due to 60 cycle hum.
- The captured SMPTE test pattern exhibited blurring of alphanumeric characters.
- The frame grabber did not capture the full gray scale range of the original image. Of the original 12 bits (4096 possible grey levels) available in the original CT image, only 8 bits (256 grey levels) were made available to the frame grabber at the modality's video out, and

only 5 to 6 bits (32 to 64 grey levels) of image information were finally acquired by the frame grabber for use within the DINS. Even if this degradation from 8 to 5 bits did not occur, the frame grabber approach would not be acceptable in a fully operational DINS. The radiologist would lose the benefit of having access to the full 12 bits of data for window width and level adjustment, and the Radiology Department would be required to maintain two separate digital archives: a tape archive for 12 bit images from the modality in addition to the DINS archive containing the frame grabber images.

Operationally, the frame grabber performed slower than standard optical multiformat cameras and newer laser film printers, which adds some delay to the image acquisition process. Further, since there was no digital interface between DINS and the modalities, there is substantial delay required due to dual entry of patient demographic data into both the DINS and the modalities.

3.6.2 Video Image Acquisition Studies at Georgetown University

The Georgetown timing studies of frame grabbing have shown typical response times under two seconds (1.5 seconds/image with version 3.0 software), which is faster than most CRT-based multiformat cameras but not faster than loading the image buffer of a laser film printer. This somewhat slower speed of frame grabbing is noticed by technologists whose cameras are faster.

Despite the problems of digitized video (and GUH agrees with UW that the artifacts, noise, and other irregularities are present), ultrasound images have proved to be of sufficient quality to be readable. In fact, the ultrasound image size, at 512 x 512 x 6 bits (typical), does not "strain" the frame grabber as much as an 800-line CT. For CT and MRI, with their larger dynamic range, digitized video is not sufficient for primary reading. It does suffice for most correlation uses.

SECTION 4

BATTLEFIELD DINS

The U.S. Army plans to implement medical imaging systems throughout its deployable MTFs in the early 1990s. The filmless environment will require an electronic management system to store, display, and transport the digital images. As part of its work for the U.S. Army Medical Research and Development Command, MITRE developed an understanding of the imaging needs of the Army's combat medical care system, and addressed these needs in a prototype Battlefield DINS. This section describes the activities MITRE performed in this part of the DINS project [8].

4.1 THE COMBAT MEDICAL ENVIRONMENT

The five echelons of medical treatment capabilities in which the Army combat medical care system is organized are characterized in table 4-1. Mobile Army Surgical Hospitals (MASH), Combat Support Hospitals (CSH), and Evacuation (EVAC) Hospitals typically contain 60, 200, and 400 beds, respectively. In one of these MTFs, the medical imaging capability is housed in a centrally-located International Standards Organization (ISO) shelter. Each X-ray module contains one High Capacity X-ray Unit (Hi-CAP) for standard radiologic and fluoroscopic exams. This equipment uses standard film cassettes, which are manually loaded into a chemical film processor. The Army is now evaluating an analog Hi-CAP unit for combat use. A fieldable CT scanner is also under development and will be evaluated for use in Echelons 3 and 4.

4.2 SYSTEM REQUIREMENTS

An initial set of functional requirements was developed from the experience with fixed facility DINS installations, and with Army input. These include:

- Image acquisition
  - Direct acquisition of digital image data
  - Electronic capture of inter-facility image data
- Image display
  - Rapid access and display of any image at any DINS workstation
  - Multiple images on a single screen
  - Adjustability of display by gray scale window width and level

Table 4-1
Characteristics of the Combat Medical Care System

Echelon	Distance To FLOT[1] (KM)	Level of Care	Number of Beds	Medical Expertise	X-Ray Capa-bility
One (Unit)	5-10	First Aid & Emergency Resuscitation	N/A	Physician's Assistant	None
Two (Division)	35	Simple Emergency Surgery	25	Several Physicians	Lo-Cap[2]
Three (Corps)	50	MASH[3]-Surgically Intensive	60	Surgeons/ Physicians	Hi-Cap[4]
	100-150	Combat Support Hospital	200 200	Physicians Including Radiologist	
	200	EVAC Hospital	300		
Four (COMMZ[5])		General Hospital	1000		
Five (CONUS[6]	1000	Teaching Hospital		All Specialties	All Modalities

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1	FLOT	Forward Line of Own Troops
2	LO-CAP	Low Capacity X-ray Unit
3	MASH	Mobile Army Surgical Hospital
4	HI-CAP	High Capacity X-ray Unit
5	COMMZ	Communications Zone
6	CONUS	Continental United States
	N/A	Not Applicable

- Ability to display image in inverse video
- Ability to rotate image
- Ability to flip or mirror a displayed image
- Ability to capture and display electronic images of patient forms
- Maintenance of image quality [21]

- Database Administration
  - Registration of new patients
  - Electronic capture of inter-facility patient data
  - Storage of all patient data on the local DINS until patient discharge or transfer

- Data Communications
  - Intrafacility transport of image data via electronic network or transportable data storage medium
  - Transportability of image data between hospitals or back to CONUS

4.3 SYSTEM DEFINITION

4.3.1 Hardware Configuration

A schematic diagram of the DINS test bed laboratory configuration is shown in figure 4-1. The non-ruggedized workstation platforms used are Sun Microsystems 3/160G and Sun Microsystems SPARC Station I. Their principal relevant characteristics are:

- 8-16 MB random access memory
- 327 MB hard disk
- 60 MB streaming cartridge tape unit
- 19-inch gray scale display, 1152x900x8 bits (square pixel) resolution

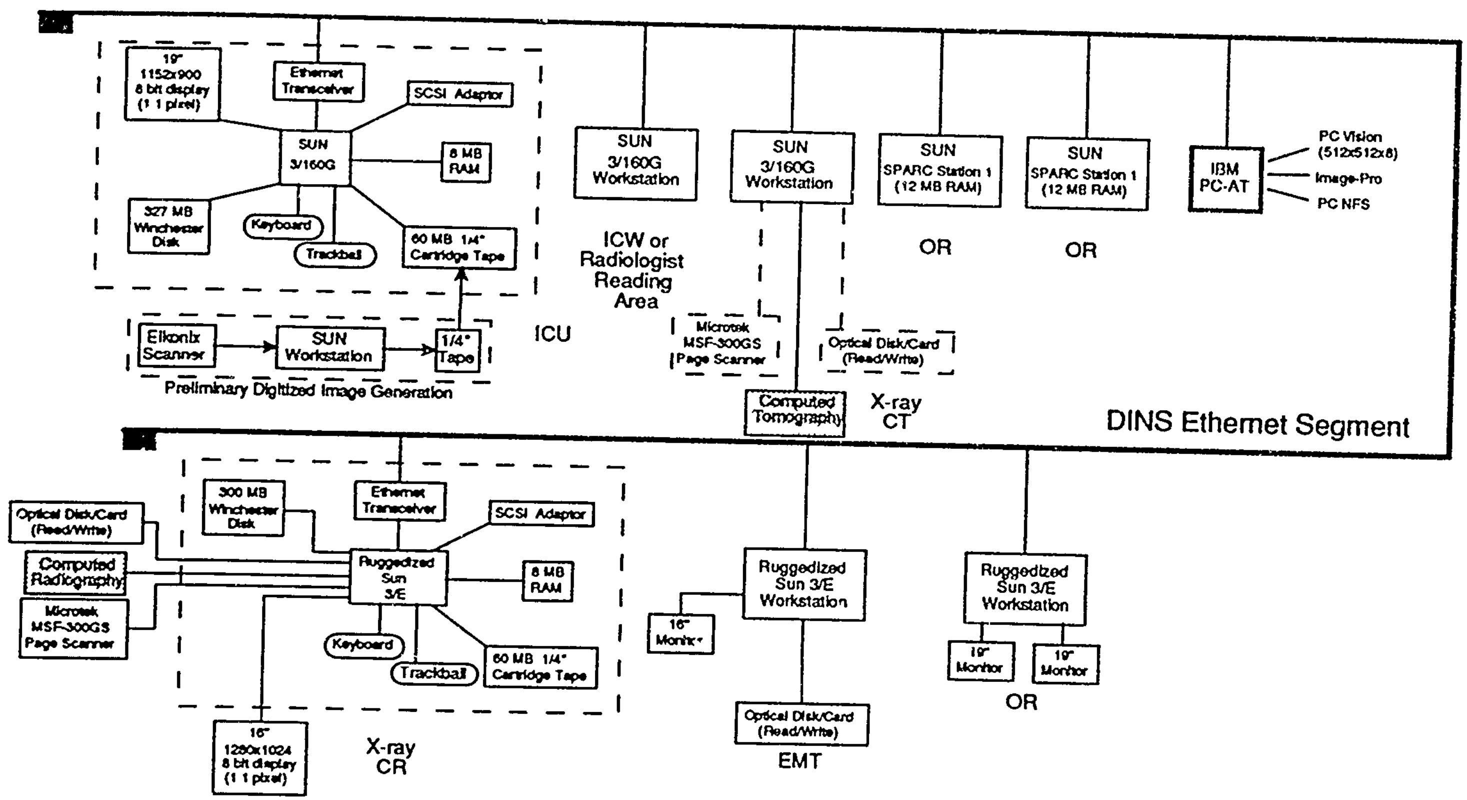

Figure 4-1
Hardware Configuration of the Battlefield DINS Prototype

- Mouse/Trackball

- Keyboard

The ruggedized workstation is an equivalent Sun 3/E equipped with a trackball. Provisions for workstation interfaces include:

- Ethernet hardware interface and software compatible with the TCP/IP protocol. Current specifications indicate that an Ethernet can handle the image data communications requirements for an Echelon 3 hospital.

- Small Computer Systems Interface (SCSI) allows future connection of a compact transportable media data storage device. Transportable magnetic and optical devices will be used for the Soldier's Interfacility Radiographic Record (SIRR) [18].

4.3.2 System Software

The battlefield DINS operating system is Sun OS Version 4.0, which is Sun's implementation of the UNIX operating system. This implementation combines the two dominant versions of the UNIX operating system, AT&T's System V and Berkeley's 4.3/4.2BSD. The display and file transfer capabilities are provided by Sun View and Network File Systems. All additional operational functions are performed by MITRE-developed software written in the "C" programming language [17].

4.4 OPERATIONAL OVERVIEW

The following sections discuss general operational features of the battlefield DINS prototype. Details of operation are presented in the user's manual for the prototype [23].

4.4.1 Patient Registration

Patients are registered in DINS either manually, by keyboard entry of pertinent demographic and medical data, or electronically by automatically reading the SIRR. When the SIRR is read, all existing images and associated patient data are read into the DINS database. This information is then available at any DINS workstation in the MTF. If a folder does not already exist for the patient, the system generates one.

4.4.2 Acquisition of New Images

It is anticipated that images will be generated directly by digital imaging modalities. Each piece of equipment will be connected directly to a DINS workstation by what will become a standard hardware interface, e.g., ACR/NEMA (NEMA, 1985).

4.4.3 Storing and Archiving Data

All of a patient's data are stored in a "folder", which is located in its entirety on one of the DINS workstation magnetic disks. When possible, the folder will be stored at the workstation considered most likely to call for the next access to the patient's data.

There is currently no requirement to archive patient medical data at the field hospital. The medical record accompanies the soldier upon return to duty or transfer to another MTF. At separation from the armed service, the entire record should be stored in a CONUS central records repository. When the patient leaves the field hospital, his DINS data are transferred from the patient's "folder", which is located in its entirety on one of the DINS workstation magnetic disks, to a SIRR, with the folder being erased from the facility's disk storage.

4.4.4 Data Transport

All locations in the MTF at which image viewing is required will be equipped with the DINS display capability. The Local Area Network (LAN) interconnection will support intrafacility data access. In the event that only a partial network or no network is established, any DINS Station equipped with a SIRR reader can display the data stored on a patient's SIRR. Current plans call for all image data to be transferred to the patient's SIRR upon transfer to another facility. Generally, the use of the SIRR simplifies the transport of patient medical image data and therefore supports continuity of care.

4.4.5 System Vulnerability

Although there are hardware differences between the ruggedized and the non-ruggedized workstations in the test bed prototype battlefield DINS, the final deployed version of the system will be of similar modular design. The use of identical interchangeable units linked via a LAN provides for ease of modifying the hardware configuration. It also greatly reduces the system's vulnerability due to failure of a critical, unique element.

4.5 EVALUATIONS OF THE BATTLEFIELD DINS

The primary aims behind integrating a battlefield DINS test bed were concept exploration and requirements definition. Two laboratory evaluations and one field evaluation provided the formal basis for the iterative design approach undertaken to accomplish these goals [22]. Informal comments and suggestions were elicited on a continuing basis as briefings and demonstrations concerning the prototype were given at a number of relevant military and civilian conferences during the year-long development period.

4.5.1 Laboratory Evaluation by MITRE Staff

The first evaluation of the DINS prototype was based on a combination of discussions between DINS project team members, various civilian and military members of the medical imaging community, and other persons familiar with the provision of combat health services. The aim of this evaluation was to conduct an informal, preliminary evaluation of the DINS workstation with respect to such aspects as functionality, ease of use, system performance (particularly display speed), and display configuration. Of utmost importance was the detection of any operational difficulties or inconsistencies. As a result of this preliminary evaluation, the subsequent evaluations were able to focus more effectively on the medical requirements of the DINS rather than become distracted with the details of software design.

4.5.2 Laboratory Evaluation by U.S. Army and University Personnel

The goals for this evaluation were similar to those for the evaluation by MITRE staff. However, this evaluation specifically focused on military field requirements. Two key questions needed to be answered:

- Do aspects such as workstation functionality, system performance, and display quality and configuration meet essential field medical imaging requirements?
- Are aspects such as hardware configuration, ease of use, user interface, operational organization, and functionality consistent with the battlefield environment and the specific needs and capabilities of battlefield health care providers?

This evaluation elicited a number of clinically useful enhancements to the prototype that were implemented in advance of the field trial, thus helping to make the field trial more realistic and useful The evaluation participants consisted of approximately 15 members of the tri-Service military, government, and academic medical imaging communities.

4.5.3 Field Evaluation at the Camp Bullis Training Facility

The prototype battlefield DINS was transported, installed, and operated at the Camp Bullis Training Facility for a one-week evaluation in a field hospital setting. The primary goals were to:

- More precisely determine the requirements for the installation and operation of DINS equipment in battlefield hospitals
- Determine functional or user interface refinements that would improve system efficacy
- Familiarize a cross-section of key military medical personnel with digital imaging technologies appropriate for use in the field hospital environment
- Gain overall experience with DINS equipment in the operational setting

The evaluation participants consisted of over 30 people with a variety of health care background perspectives from the U.S. Army, the Australian Armed Forces, industry, and academia. This evaluation elicited a number of clinical suggestions critical to a successful clinical implementation of DINS on the battlefield. Practical issues concerning system transport, installation, and maintenance were also brought to light.

4.5.4 Summary

Overall, the workstation and electronic network technology incorporated in the prototype provided acceptable display quality and system performance for use in Echelon 3 and 4 health care facilities. The prototype demonstrated that functional completeness could be achieved in concert with operational simplicity. Appropriate system ruggedization should be possible through the use of rugged packing materials and/or ruggedized system fabrication techniques; however, a review should be conducted by military hardware experts to better determine the physical ruggedization requirements of the DINS hardware. Many of the questions pertaining to various operational and implementation issues have necessarily been deferred until the DINS is interfaced to a digital imaging modality and a clinical trial can be performed.

4.6 SIGNIFICANCE OF THE BATTLEFIELD DINS PROTOTYPE

The battlefield DINS test bed allowed the demonstration of DINS's capabilities to manage digital image data in a battlefield MTF. The nature of the hardware and software which comprised the prototype was such that various operational functions (e.g., the use of image processing algorithms such as histogram equalization and unsharp masking) and new technologies (e.g., optical disks) could be conveniently evaluated to determine if they should be part of a specification for a battlefield DINS.

Individuals with various backgrounds and interests were able to effectively comprehend and use the system with less than 30 minutes of instruction. Given the excess data storage, analysis and management capacity inherent in the computer workstations and electronic network that comprise the DINS, the possibility of integrating all of a soldier's medical data into the DINS was suggested. The potential usefulness of providing access to general medical expert systems via the DINS was also suggested as a means to augment the capabilities of the medical staff, particularly in the more forward echelons. This prototype system will provide the means to allow future exploration of these advanced concepts for incorporation into the specifications for the DINS that will be eventually fielded.

4.7 SYSTEM SIMULATION

MITRE developed a simulation model to help define the requirements for future battlefield DINS. This model was used to simulate the flow of casualties through the Army combat health care system. The model provided estimates of DINS data storage requirements, the impact of LAN utilization on delays in displaying images, and estimates of the capacity requirements of the SIRR.

utilization on delays in displaying images, and estimates of the capacity requirements of the SIRR. The principal relevant attributes of the health care system being simulated are described in section 4.1 [10]. The flow diagram for the movement of casualties through the combat health care system is shown in figure 4-2.

4.7.1 Model Description

The simulation model focused on the EVAC hospital in Echelon 3 as this is the lowest echelon at which DINS is expected to be introduced. Image use for triage and surgical planning is urgent and critical at this level. The model follows the movement of a casualty through the battlefield medical system and analyzes, in detail, casualty movement through the EVAC hospital wards:

- Emergency medical treatment ward (EMT)
- X-ray and CT units (X-ray)
- Operating room (OR)
- Intensive care unit (ICU)
- Intermediate care ward (ICW)
- Minimum care ward (MCW)

The nature of the injury (selected from a random distribution function) is used to determine the length of stay in the wards and the number of X-ray images generated [19]. It is assumed that a patient's electronic folder of images is stored on a workstation in or near his ward. This means that when a patient moves, the folder is transferred to the new ward over the LAN. The LAN protocol used is equivalent to carrier sense multiple access (CSMA) with access requests queued to prevent collisions. For low utilization of the LAN, the results are consistent with the performance of an Ethernet LAN.

The rate at which casualties enter the simulated health care system was adjusted to cause a significant queuing in the EVAC hospital OR. This criterion was used to establish a maximum loading on the hospital DINS. Casualties could be entered into the hospital at a greater rate, but from a medical care standpoint, this would be impractical.

Output generated by the model detailed the number of medical images stored within the hospital wards and the utilization of the LAN. Specific outputs include:

- Average number of images stored in each hospital
- Average number of images stored in each EVAC hospital ward

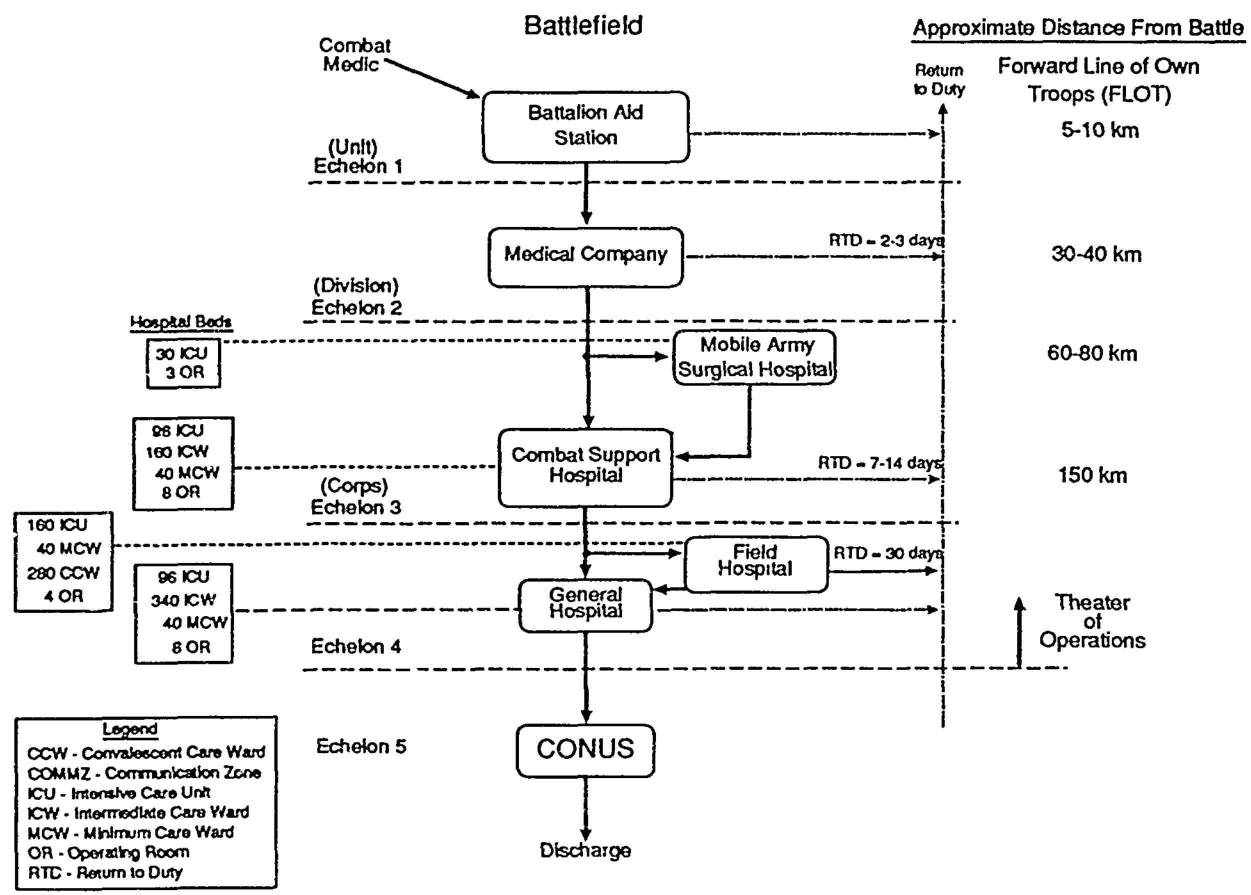

Figure 4-2
Casualty Flow through the Five Echelons of Combat Care

- Number of images stored versus time over the time period simulated
- Average and maximum delay encountered by workstations attempting to send images over the LAN
- Average size of image files transferred over the LAN and between hospitals

In addition to the means and extreme values indicated above, the model generates frequency distributions of the output parameters.

4.7.2 Results of the Simulation

Simulation results on the peak number of images actively stored in each EVAC hospital ward and in the hospital as a whole are given in table 4-2. Assuming that a 1024 x 1024 x 12 bit image requires 1.5 Mbytes of storage space, table 4-2 also gives the peak active storage requirements.

Table 4-3 presents results on the number of images transferred to Echelons 4 and 5 when casualties are evacuated to rear areas for further treatment and recuperation. These images can be carried with the patient on a SIRR.

In order for a medical provider to be able to view an image on a workstation within a few seconds of making the request, any images transferred between workstations over the LAN must be sent at a high data rate. In the simulation, a LAN data rate of 8 Mbits per second was used. The average time between requests for any workstation to send images over the LAN is 12 minutes, which is a low relative data throughput requirement for a LAN with such a high data rate, and contention for access to the LAN should be rare. However, occasionally, the simulation found that the LAN was busy when a request to send images was made, causing a transmission delay. The simulation output indicated that 99 percent of the time a workstation encountered a transmission delay of less than one-half second (the minimum resolution of the measured delay), with a maximum delay greater than one second occurring only 13 times out of the total of 1,540 requests made. The longest delay was 11 seconds. Since the LAN used in the model closely resembled a 10 Mbits per second Ethernet, this type of LAN should easily satisfy the inner-workstation communication needs for the hospital in this example.

The input data have been modified to include the use of CT exams for certain types of injuries. These CT exams generate images that have significant diagnostic value but require a large amount of digital storage capacity. For this simulation, it is assumed that the storage requirements for a CT exam are ten times that of a single x-ray (i.e., 40 CT slices at a resolution of 512 x 512 pixels by 12 bits per pixel.) Table 4-4 compares the peak storage requirements for X-rays only with the requirements for X-rays plus CT exams. Table 4-5 compares the effect on number of images accompanying evacuees to Echelons 4 and 5. The introduction of CT diagnostic imaging in an EVAC Hospital increases the peak storage requirements by about 40 percent.

Table 4-2
Peak Image Storage Requirements in an EVAC Hospital

Workstation Locations	Peak Number of Images Stored	Peak Storage Requirements (MBytes)
XRAY	20	30
OR	310	465
ICU	762	1,143
ICW	514	771
Total for Hospital	1,398	2,097

Note: The peak number of images stored in the wards does not add up to the total for the hospital since ward peak values are not reached simultaneously.

Table 4-3
Images Transferred to Echelons 4 and 5

	Number of Images	Storage Requirements (MBytes)
Transferred to Echelon 4	3,441	5,162
Transferred to Echelon 5	3,553	5,330

Table 4-4
Comparison of Peak Storage Requirements for X-Rays Only and for X-Rays Plus CTs

Workstation Locations	Stored Images (MBytes)	
	X-rays Only	X-rays Plus CTs
XRAY	30	83
OR	465	723
ICU	1,143	1,791
ICW	771	1,080
Total for Hospital	2,097	3,074

Note: The peak number of images stored in the wards does not add up to the total for the hospital since ward peak values are not reached simultaneously.

Table 4-5
Comparison of Images Transferred to Echelons 4 and 5 for X-Rays Only and for X-Rays Plus CTs

	Images (MBytes)	
	X-rays Only	X-rays Plus CTs
Transferred to Echelon 4	5,162	7,119
Transferred to Echelon 5	5,330	7,515

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Evaluations conducted under the DINS project demonstrated that there are no basic flaws in the DINS concept but that some technical improvements are required for such systems to be considered technically and clinically acceptable. These enhancements are not beyond the capabilities of existing commercial technology.

Specific conclusions are grouped together below regarding clinical acceptability in the fixed facility environment, technical acceptability in the fixed facility environment, and general conclusions following the evaluations of the DINS battlefield prototype.

5.1.1 Clinical Acceptability of Fixed Facility DINS

Following are positive attributes of DINS drawn from the university evaluations in fixed facility medical environments:

- Access to and availability of images are improved.
- Images in digital form can be interactively processed and enhanced.
- Consistency of images is improved over time, primarily due to CR.
- CR is tolerant of poor exposure procedures; as a result, retake rate and radiation dose to patients can be reduced.
- Multi-modality data can be co'' cted more quickly and easily.
- Fewer films and folders are lost.
- Multi-location access to an image promotes remote consultation.

Furthermore, time savings were reported by users of DINS in the ICU at Georgetown University, and the travel burden to an on-call radiologist was reduced via a teleradiology link to his house.

5.1.2 Technical Acceptability of Fixed Facility DINS

The DINS equipment evaluated under the DINS project was found to be technically acceptable to system users, with some reservations. Principal concerns were a lack of user friendliness, less than satisfactory reliability of the system, and, at the University of Washington, less than satisfactory speed of operation due to system bottlenecks. At Georgetown University, the operational speed of the system was reported to be less of a problem. It should be noted that, in the later stages of the evaluation, the Georgetown system supported "Turbo" workstations and auto-routing. The "Turbo" workstations were significantly faster than those used at the University of Washington. Auto-routing sent newly acquired images immediately to the appropriate viewing stations based on the modality of the exam rather than requiring users at the viewing stations to request the retrieval of exam images. These capabilities appeared to make the system seem faster for some operations when, in actuality, the system at Georgetown University was found to provide lower overall throughput than the system at the University of Washington.

5.1.3 Needed Improvement in Fixed Facility DINS

Although there were no insurmountable technical flaws identified, room for improvement in DINS was reported.

- Areas where the equipment was found to be lacking include:

  - Display speed--The general guideline for acceptability seems to be that the system throughput should be such that a radiologist is as productive, if not more productive, using DINS than working in a conventional film-based radiology department. While significant delays were experienced with early versions of the system, the addition of the Turbo workstation and the auto-routing of images significantly improved system performance. In the Georgetown experience, the improvements in speed and storage capacity of the "turbo" EGDW made it acceptable as a clinical tool, at least for primary reading of ultrasound studies. Early testing with other radiologists has shown that it will probably also be sufficient for body and head CT reading, but additional monitors may be needed for MRI interpretation.

  - Stability--It is essential that the system function reliably and predictably. The original technical specification called for availability on the order of 98 percent. If a DINS is to function satisfactorily in a fully operational environment, this requirement must be met or exceeded. This availability requirement applies to DINS functionality and not necessarily to the reliability of each individual DINS subsystem. For example, a single workstation failure can be tolerated provided all of the work that is normally done at that workstation can be completed at another workstation without seriously disrupting the department's workflow.

- Image acquisition--Direct digital interface to the digital imaging modalities (CT, CR, MRI) is required. The analog video frame grabbing technique used in this evaluation was technically evaluated and found to be unacceptable due to degradation of the acquired images. In addition to degrading the overall image quality, the frame grabber approach does not allow capture of the full 12-bit images from the modalities so that window width and level adjustments can be made at the DINS workstations. Further, this approach requires the maintenance of dual archives for each modality: a 12-bit tape archive and an 8-bit DINS archive.

- Interfaces to other systems--While early versions of the system software caused significant delays in transferring data between DINS and the RIS/HIS, later software versions corrected these problems, and resulted in significant performance improvements.

- Other weaknesses identified in the evaluation of the fixed facility DINS included:

  - Lack of an intuitive user interface

  - Insufficient image resolution for some modalities

  - Documentation lacking in content, consistency, and accuracy

- From the evaluations conducted under the DINS project, it is clear that a two-way, reliable interface is required between DINS and a RIS or HIS. If the interface fails, both systems must remain operational with both automatic and manual procedures in effect to insure integrity of the DINS and RIS/HIS databases.

- Interfaces to the imaging modalities (CT, CR, MRI) must be digital and must support the automatic transport of both patient images and demographic information. Dual entry of demographic data is error-prone, time-consuming, and generally unacceptable.

- Issues still pending regarding fixed facility DINS include the following:

  - Acceptable image display resolution needs to be defined for CR

  - Use of image compression (reversible versus irreversible) must be resolved

5.1.4 Conclusions Regarding DINS in the Battlefield

From the evaluation of the prototype battlefield DINS developed and evaluated under the project, the following conclusions were reached:

- Current workstation technology provides acceptable image resolution and system performance for use in Echelons 3 and 4 combat medical facilities.

- DINS equipment can be made to survive in the battlefield environment through either ruggedization of the equipment or the use of rugged packing material.

- A simple user interface is preferred in this environment.

- An affordable digital medium for transporting images between battlefield hospitals is not available at this time.

5.2 RECOMMENDATIONS

Recommendations are grouped below with respect to implementations of DINS in fixed facilities and in the battlefield.

5.2.1 Recommendations Regarding Fixed Facility DINS

- DINS is now ready to be phased into installations on a limited basis. Such phase-ins should be subjected to operational evaluations to determine the effect they may have on the operations. While the systems evaluated under the DINS project yielded data on the performance and requirements for future DINS, the systems were experimental and were operated largely in parallel with existing radiology department operations.

- Efforts should continue to make DINS operational, and close attention should be paid to the issues of user interface, speed of operation, and reliability when developing future specifications.

- Quality assurance and testing tools (preferably automated) are required and must be specified as part of any DINS.

- Redundancy must be built into the system to reduce downtime. A system upgrade path must be well-defined with modular implementation, and upgrades must not result in substantial downtime.

- Significant advanced planning is essential. It is easy to underestimate the amount of effort required to educate users and general hospital community and to plan and coordinate the installation.

- A DINS/CHCS functional description must be prepared if DINS is to be used in military hospitals

- Cost/benefit models should be refined as operational DINS are implemented.

- Redundant parallel operations using film should be phased out as quickly as possible in fixed facility operations so that DINS can be evaluated as a stand-alone capability.

- Standards must be developed for image and patient demographic data transport between field and fixed facility (standard media, file format, file structure).

- Common interface standards should be employed at each external interface with the system including:

  - interface to the modalities
  - interface to the RIS/HIS
  - open interface for research applications and for evaluation of future capabilities
  - interface to other facilities via teleradiology
  - open systems interface

- Given the rapid pace with which improvements in technology are made, DINS equipment procurements should include options for future upgrades so as to avoid obsolescence.

- Support of DINS requires the addition of technical personnel not currently included in a typical radiology department's staffing. The need for such staff must be addressed in planning for and estimating the costs of DINS.

- The following recommendations pertain to training and user support:

  - System messages to users must be informative, void of computer jargon, and offer the user some assistance if further action is required.

  - User's actions must be acknowledged, especially if lengthy delays are involved (e.g., requests to move large folders across the network). The user must never be left in a position of wondering if the system has frozen or is merely carrying out a lengthy operation.

  - On-line help files are essential

  - User's manuals must correctly reflect the current version of the system.

  - System acceptance testing should include criteria for completeness and correctness of the documentation (e.g., manuals, quick reference cards, on-line help files).

  - Video taped training may be useful.

5.2.2 Recommendations Regarding DINS in the Battlefield

Following are recommendations regarding the future use of DINS in the battlefield:

- Environmental and ruggedization requirements must be further defined for the workstations and CR equipment.
- A fully integrated battlefield DINS prototype, including CR and CT, should be subjected to formal evaluations under field conditions so that final technical specifications can be prepared for future procurements of this equipment.
- Interoperability between battlefield and fixed facilities is required.
- Protocols for image storage and format for the battlefield transportable media should be consistent with requirements for fixed facility DINS equipment to insure interoperability.
- Additional uses for the DINS workstations and network in the battlefield environment should be explored (e.g., support for the Joint Theater Medical Information System, medical logistics support, records management.)
- Further cost analyses should be conducted for DINS in the battlefield environment as mission requirements change and as new organizations for field medical operations evolve.

5.3 GENERAL PROJECT CONCLUSIONS

Following are general conclusions reached under the DINS project:

- DINS will not be accepted operationally until interfaces to the modalities (CT, CR, MRI) are fully digital and their operation is transparent to the users of both DINS and the imaging modality hardware.
- A fully functional interface between DINS and HIS/RIS remains a problem and is a key issue for operational acceptance.
- If DINS is to coexist in military medical facilities with CHCS, an interface must be defined so that DINS can be adapted to the CHCS environment, CHCS can be modified to interact with DINS, and DINS can be specified and procured with a proper interface.
- While still expensive, DINS implementation costs may drop significantly, following workstation technology cost trends, making an operational DINS more feasible from a cost viewpoint.

- Teleradiology is reaching the point where it is both operationally acceptable and cost justifiable.

- Speed of display and ease of operation are critical to user acceptance.

5.4 GENERAL PROJECT RECOMMENDATIONS

Given the above conclusions, the following general recommendations are made:

- Evaluate DINS in an operational, military, fixed-facility setting.

- Phase the implementation of a DINS. Do not attempt to reconfigure an existing radiology department in one operation.

- Use CR as the main source of plain film images for DINS.

- Develop a Functional Description (FD) for a DINS/CHCS interface.

- Continue to develop and evaluate the battlefield DINS prototype. Once a fully operational prototype has been formally evaluated in an operational environment, technical specifications can be prepared.

Appendix A

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GLOSSARY

ACR	American College of Radiology
AM	Acquisition Module
AT&T	American Telephone and Telegraph
CAT	Computer Aided Tomography
CC	Consultation Console
CHCS	Composite Health Care System
COMMZ	Communications Zone
CONUS	Continental United States
CR	Computed Radiography
CRT	Cathode Ray Tube
CSH	Combat Support Hospital
CT	Computed Tomography
DECrad	Digital Equipment Corporation Radiology Information System
DEMPEDS	Deployable Medical System
DINS	Digital Imaging Network System
DoD	Department of Defense
EGDW	Enhanced Graphics Display Workstation
EMT	Emergency Medical Treatment
EVAC	Evacuation Hospital
FD	Functional Description
FIDS	Filmless Digital Imaging System
FLOT	Forward Line of Own Troops
GUMC	Georgetown University Medical Center
HI-CAP	High Capacity X-ray Unit
HIS	Hospital Information System
HSS	Health Services Support
ICU	Intensive Care Unit
ICW	Intermediate Care Ward
ID	Identification
IFD	Interface Functional Description
IMACS	Image Management and Communication System
ISO	International Standards Organization
JOTMIS	Joint Theater Medical Information System

LAN	Local Area Network
LO-CAP	Low Capacity X-ray Unit
KBPS	Kilobits Per Second
MAMC	Madigan Army Medical Center
MASH	Mobile Army Surgical Hospital
MB	Megabytes
MBPS	Megabits Per Second
MCW	Minimal Care Ward
MF2K	Medical Force Two Thousand
MIC	Montgomery Imaging Center
MIIS	Meditech Interpretive Information System
MRI	Magnetic Resonance Imaging
MTF	Medical Treatment Facility
MTR	MITRE Technical Report
MUMPS	Massachusetts General Hospital Utility Multi-Programming System
NEMA	National Electrical Manufacturer's Association
NMR	Nuclear Magnetic Resonance
OR	Operating Room
PACS	Picture Archiving and Communication System
PCR	Philips Computed Radiography
PDIP	Program Decision Increment Package
PET	Positron Emission Tomography
Rad	Radiological
RIS	Radiology Information System
ROC	Receiver Operating Characteristic
RTD	Returned to Duty
RVS	Results Viewing Station
RVU	Remote Viewing Unit
SCSI	Small Computer Systems Interface
SIRR	Soldier's Interfacility Radiographic Record
UCA	Uniform Chart of Accounts
USAMRDC	U.S. Army Medical Research and Development Command
UWMC	University of Washington Medical Center
WORM	Write Once, Read Many
VAMC	Veterans Administration Medical Center

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Annual and Final Report

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